THE

JOURNAL OF GEOLOGY

JANUARY–FEBRUARY, 1905

GLACIAL FEATURES IN THE SURFACE OF THE ALPS[1]

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The study of river action has been very much advanced in the Alps, whose torrents give magnificent examples of the destructive and constructive action of running water. But the surface features of this great European mountain chain do not all correspond to those which we might expect after a careful study of river action. Rivers seek to establish a normal curve, which grows continually gentler down-stream. The valleys of the Alps, however, do not show such a regular grade. The floors of the headwaters show many irregularities, and gentle grades alternate with steep ones. Instead of a slope curve, there is a succession of descending steps. Farther down we find for several miles a valley floor sloping normally; this floor has been aggraded by the river and often ends in a lake basin, where the normal slope is changed into a reversed one. Most of these features are not produced, but rather are destroyed, by river action. Indeed, we see how the rivers intrench themselves in the steep parts of the stair slope, and how they fill up the lakes, which generally occupy the lower part of their valleys in the Alps. In short, their action is directed toward removing the irregularities of their courses.

There is still one other important point in which the slope of Alpine valleys does not obey those rules which control normal valleys; the law of Playfair is not applicable to them. The mouths of the lateral

[1] This paper contains some results to which the author has arrived by researches on the Great Ice Age in the Alps, carried on together with Professor Brückner, of Halle. A detailed account of this study is given in a book entitled *Die Alpen im Eiszeitalter* (Leipzig: Tauchnitz). A part of the paper was read at the International Geographical Congress at Washington, September, 1904.

valleys are usually not accordant; they do not lie at the level of the main valley, but at a higher level; their rivers often tumble down in waterfalls to join the master-river, or they have cut into the floor of the lateral valleys a deep gorge, through which they whirl, and rush to reach the bottom of the main valley. These are the very well-known *Klammen* of the eastern, and the "gorges" of the western, Alps; and many waterfalls of this mountain chain lie at the mouths of the side valleys.

The cross-sections of our Alpine valleys are also other than what one might expect. The master-valleys have in general an extended flat bottom, at the sides of which rise very steep walls. At a certain height, steep slopes below change into more gentle ones above. Well-marked ledges separates the two slopes, and form distinct shoulders on both sides of the valleys—a condition not usually found elsewhere. That part of the valley which lies below the shoulders has often a trough-like appearance. The trough extends upward to that region in which the aggraded valley bottom is succeeded by a series of descending rocky steps, and here is often formed a very striking trough's end, by the cliff side of a high step. Above the shoulders the valley slopes are far from being regular; often they form cirque-like niches, at the bottoms of which little tarns occur. These are the *Kar* of the Alps, the "corries" of Scotland.

There are certain rules which control the occurrence of all these features. The heights at which the side valleys terminate above the main valley show a pretty regular arrangement. They describe a curve which slopes down regularly between the height above the trough end and that point where we meet with the last part of the reversed slope of the valley floor. The shoulders show a similar, but less regular, arrangement; they are also limited by the trough's end and the end of the last reversed slope of the valley floor; their height also decreases, though not regularly, between these two points. The whole arrangement leads to the conclusion that the trough has been excavated in an older valley with a higher floor; the shoulders are the intersections between the trough sides and the side slopes of the old valley. The hanging side valleys are parts of the old valley system which suffered little from erosion, and conserved their original depth. This condition is now generally accepted, since the connection

of all these phenomena has been recognized, but this conclusion is not in harmony with ideas which prevailed for a considerable period, when only *one part* of the irregularities of Alpine valleys was taken into consideration.

For some time the great Alpine lakes have been regarded as the only irregularities of the Alpine valleys, and the questions of Alpine geomorphology have included only the formation of the great Alpine lakes. Of the different ways in which valley lakes are formed, only two have been considered; namely, the hypothesis of warping and the hypothesis of glacial erosion presented by A. C. Ramsay. In order to understand the former, let us assume that the lower part of a normal river slope was elevated, or the upper part was depressed. The normal slope curve then would be changed into a curve with an ascending part having a reversed slope, and the part limited downstream by this reversed slope would be filled with water so as to become submerged. This idea, first suggested by Sir Charles Lyell, and later developed further by Rütimeyer and Heim in Switzerland, helps us to understand the transformation of some valleys into lake basins; but it leads to consequences which are not supported by observations in the field. Earth-movements which could reverse the slope curve of a master-river must also affect its branches; and if a part of its curve is depressed to form a basin, the affluents of this part must also be depressed, and their lower courses must be submerged in a manner similar to the basin formed by the depression of the floor of the master-valley. Lakes formed by the subsidence of part of a river valley must digitate into the side valleys. Contrary to this, the side valleys of the great Alpine lakes are not drowned at all, but they are hanging above the lakes, and their floors show no traces of depression. The digitations we find now and then in Alpine lakes have nothing to do with the drowning of true lateral valleys; they do not stretch toward the mountains from which the side valleys come, but extend in the opposite direction. They are related to the frequent valley bifurcations, which will be considered later.

The basins of the great Alpine lakes occupy only a part of the troughs of the Alpine valleys, and every hypothesis as to their formation must deal with the trough. The trough bears every evidence of

having been eroded in a former river basin, the side branches of which suffered less lowering than the main branches. This fact is now generally admitted by all who have studied the relation between the high-hanging valleys and the main valley, and it is generally acknowledged that the latter, in comparison with the former, has been overdeepened by erosive action. But there is still a diversity of opinion as to this action. Some authors, like Kilian, Garwood, and Frech, believe that it has been exercised by rivers, while the hanging valleys were occupied by glaciers and protected by them against the erosive action of water.

This idea ascribes to river-action phenomena such as are usually not developed by it. The trough does not bear the features of a common river valley; it has the width to which river valleys attain in their maturity, but it has not the normal grade which rivers always have in this phase of their development. Their slopes have the steepness of youth, as is proved by innumerable landslides occurring along them. It is a peculiar association of young and mature valley features we meet with in our large Alpine, trough-like valleys—an association which cannot be understood by the assumption of normal river action; and no attempt has been made until recently to show how it was brought about by rivers. As to the hanging valleys, however, there are not a few cases in which they were not occupied by glaciers. Therefore glacial action protecting their bottoms cannot have caused the elevation of their bottoms above those of the main valleys. The hanging valley is not a feature characteristic of glaciated regions only, the hanging mouth being confined to the latter.

He who wishes to examine the Alpine valleys in the light of river-work must not first take the valley floors into consideration; he must observe the river channels. There the law of Playfair has no application. While in the state of their maturity the surfaces of two rivers unite at the same level, their bottoms will not do so; the bottom of a larger, deeper stream generally lies deeper than that of its smaller and shallower affluent. The bottoms of side-river channels are hanging above those of the main rivers. We have here steps at the mouths, as in the Alpine valleys. While the surfaces of rivers grade down continually, their bottoms show irregularities which resemble those of the floors of some Alpine valleys. The forms of mature valleys

are determined by the laws which control the *surfaces* of moving liquids, while the forms of the Alpine valleys are governed by the rules controlling the formation of the *floors* of moving liquids. Thus, instead of the law of Playfair, the law of adjusted cross-sections comes into action.

There can be no doubt what particular moving liquid or quasi-liquid is related to the features of the Alpine valleys, since it has been recognized that all the greater Alpine lakes lie in the region of the old glaciation, and later researches have proved this for all the special features of Alpine valleys. The overdeepening, with all its accompanying features—the trough, the trough's end, and the lake lying in it, with its shoulders and the hanging mouths of side valleys—is confined to the area glaciated during the Great Ice Age, and the moment you leave this area you reach the normal features of mature valleys with accordant mouths of side streams; you reach mountains whose summits are not dissected by corries. The concurrence of Alpine valley troughs and old glaciers suggests the theory of origin by glacial erosion. The theory of glacial erosion was advanced by A. C. Ramsay for the formation of the Alpine lakes. We go a great deal farther than he when we apply that theory to the formation of the far more extended feature of the troughs in the Alpine valleys, for the lake basins occupy only those parts of the troughs which extend below the lowest parts of their circumferences.

The erosive action of the glaciers has very often been denied, and is even now denied by some, while it has been at various times vigorously supported. This diversity of opinion is caused by the fact that we cannot observe how actual glaciers act upon their bottoms, their work being concealed by their icy mass. We usually see only how the glaciers transport moraines and deposit them about their lower ends. The fact that stone avalanches not rarely fall down from the side walls of a valley on the surface of a glacier suggested the idea that the material of the surface moraines is due entirely to the action of weathering exercised on those cliffs which overlook the glacier. The study of the moraines on actual glaciers, however, has revealed more clearly the fact that they cannot be entirely derived from those cliffs, but that they come in large part from the bottom of the glacier. What effects are here produced by the glacier can be observed only

at those places which have been covered by the ice for some time, and then revealed again. Here we observe those very well-known *roches moutonnées*, polished and striated surfaces, which dip gently in the direction from which the glacier came, but which terminate abruptly in the opposite direction. In general, the rock surface is here limited by joints. It cannot be longer maintained that we have at those places the original surface of the rock before us. We stand rather before a quarry from which rock fragments were broken out and plucked away. This can be proved now and then by observation. At the Hornglacier in the Zillerthal Mountains, for example, I found near a *roche moutonnée* fragments which had been plucked out there and transported by the ice for some distance, slightly upward. They fitted perfectly into the quarry from which they were taken. Thus the *roches moutonnées* teach us that glaciers do not exercise a scouring action alone on their beds, as generally stated, but that they also effect a quarrying and plucking action, which is not always recognized. Therefore we will no longer call the two sides of a *roche moutonnée* "push side" and "lee side," but we prefer the expressions "scour side" and "pluck side," introduced by Shaler. Plucking forms the most important part of glacial erosion; it is exercised as well on the bottom as on the sides of its bed, and since the glacier can also transport fragments upward, it is enabled to adjust its bed to its mass and its movement.

The adjustment of its bed to its mass and movement is not confined to glaciers; the same occurs in rivers. The difference lies partly in the fact that the glaciers' beds, on account of the slowness of glacier movement, are far more conspicuous than the beds of rivers of equal capacity. The adjustment to which we refer is controlled by the necessity that through a given cross-section of a river or of a glacier must annually move the whole quantity of run-off or ice produced in the corresponding catchment basin. There is therefore a relation between the size of cross-sections (Q) and the mean velocities (V) of the liquids, on the one hand, and of area (A), precipitation (p), and evaporation or ablation (e), on the other, which may be expressed by the following equation:

$$VQ = A(p\text{-}e).$$

If there are no sudden changes either in the velocity of the moving bodies—those changes will always disappear in the course of time—or in the precipitation and evaporation or ablation of a certain region, then neighboring cross-sections will increase in the same way as the areas do. They will be nearly equal in size, if there is only a slight increase of the catchment basins between the two sections; they may be rather different if a sudden increase of the catchment basin occurs. If, for example, a river or glacier gets an important affluent, there will be a rapid increase in the size of its cross-section.

The arrangement of neighboring cross-sections is controlled by the fact that the surface of the moving liquid must have a slope. Their surfaces must continually decrease in height when we follow the direction of the movement, and where two moving fluids unite their surfaces must join at the same level. The surfaces of glaciers as well as the surfaces of rivers obey the law of Playfair, but their channels conform at the same time to the law of cross-sections. The large cross-section of a main river or a main glacier, as well as the smaller cross-sections of their affluents, have accordant surface junction, and therefore their bottoms must have different heights as long as the cross-sections are similar to each other, which is in general the case. The bottoms of side streams hang above the bottom of many rivers in the same way as the bottoms of side glaciers hang above the bottom of main glaciers. The hanging mouth is a feature of the bottom of moving liquids; the accordance, a feature of their surfaces. Since the river surfaces are the base levels of the country along their sides, they govern the heights of the bottoms of the valleys, which therefore, obey, the law of Playfair.

Every river bed shows inequalities which may be compared with the inequalities of the glacier bed. There is, however, one very marked difference. Most rivers constantly grow, and their cross-sections become therefore larger and larger. On the other hand most glaciers grow only to a certain limit; then they decrease by ablation until they terminate. Therefore their cross-sections will increase at first and then decrease. In a simple glacier the maximum cross-section will be found just at the snow-line; in a composite one, it may occur farther downward. Above and below this maximum cross-section the surfaces and bottoms of the cross-sections will

approach one another until they finally coalesce. While, however, the surfaces must be arranged in a descending order, the same is not the case with the bottom. It is stated from observation that glaciers can also move on reversed slopes as long as they have a sufficient surface slope; that is, as long as the surface slope is considerably greater than the reversed bottom slope. To keep up glacial movement, it is necessary that the curves of successive cross-sections be arranged in a descending order. If we therefore, have, at the lower end of a glacier, a series of cross-sections of diminishing size, their bottoms may rise, if their surfaces slope so steeply that their centers of gravity form a continually descending line. Therefore we find in the bottoms of glaciated valleys reversed slopes, and we must expect to find them chiefly near the ends of the old glaciers. Here, indeed, most of the larger lakes of the Alps are found.

The general arrangement of the Alpine glaciation during the Great Ice Age was the following: The interior valleys of the mountain chains were filled up with enormous, flat cakes of ice, of 2,000–2,500 m elevation, interrupted by the higher ridges, from which deep affluents poured into the *mer de glace*. Its surface sloped down in the center very gently, and with increasing steepness toward its rim. Under this steep marginal slope lie the existing and former lake basins of the Alps. The location of their reversed slopes indicates the region where the glacier's erosive action gradually ceased. It has long been recognized that the depth of these lakes is far greater in the south than in the north, but no adequate explanation has been given. This phenomenon is consistent with the fact that the marginal slope of the Alpine glaciation at the south side of the mountains was twice or thrice as steep as on the north side; here a far greater reversed slope could be overcome by the glaciers. It must be borne in mind, however, that thick morainic deposits occur at the lower ends of the troughs. The lake basins of the Alps, therefore, are not alone formed by glacial erosion; they are partially dammed up by the thick gravel deposits which the glaciers accumulated at their ends, and this accumulation assumes, in the south side of the Alps, a far greater thickness than on the north side, because it is concentrated over a less extended area. This damming up raises the levels of the Italian lakes far higher than those of the south German lakes, and the differ-

ence of the depths of those lakes is partly caused by this difference of accumulation.

The rule of the cross-sections helps us to understand not only the formation of the lake basins in Alpine valleys, but also how the trough's upper end was formed. We usually find it where there was a confluence of the glaciers in the upper parts of a valley, where the slope glaciers united to form the valley glacier. The mass of ice, coming from this semi-circular head, was pressed here into the diameter of the same circle. Now, in order to maintain a continuous movement, an increase of velocity was necessary at this place. This increased velocity must act on the bed of the glaciers until a sufficient depth is attained. Theoretically this depth must be 57 per cent. (that is, $\frac{\pi}{2} - 1$) greater than at the semi-circle from which the glaciers came.

The cross-sections of glacier-beds are in general, as was recognized long ago, U-shaped, which indicates that a certain relation between width and depth is the most appropriate one for the glacier's movement. This U-form is, however, only constant in homogeneous rocks. In places where there are sudden changes in the nature of rocks, we meet with changes in the shape of the trough. At those places we observe that the glaciers exercise a very strong selective erosion on their bottoms. Some rocks resist more than others, and here the glacier bed shows a remarkable adjustment to the nature of the rocks. Many steps in glaciated valleys are caused by highly resistant rocks. Now and then, but not at all regularly, an increase of width corresponds here to the decrease of depth of the glaciated valley. Conversely, a sudden increase of width in a glaciated valley is often connected with a diminution in the depth of the trough.

The study of the old glaciers of the Alps reveals that, as far as their movement is concerned, they consist of two parts. In their upper parts, where they were fed by numerous affluents, there was a *confluence* of ice in the main valleys corresponding to the confluence of waters which occurs there now. In their lower parts, however, they no longer received lateral affluents. Here they spread out fan-like on the plains at the foot of the mountain chain, or even in its interior, penetrating into those valleys which afforded them no affluents.

Regions of glacial *confluence* and glacial *diffluence* are sharply separated from each other. They have nothing to do with the feeding and melting part of the glacier, and are determined only by the presence or absence of lateral affluents. The confluence and diffluence of glaciers, therefore, may occur as well in its névé region as in its region of ablation, in its feeding, or in its dissipating part (according to H. F. Reid), but generally the confluence prevails in its upper parts and the diffluence in its lower parts. On the north side of the Alps the diffluence is excellently represented by the enormous ice fans in the German Alpen-Vorland, where formerly were the glaciers of the Rhine, the Isar, the Inn, and the Salzach, while in Switzerland the diffluence was hindered by the Jura Mountains so that no regular fans were formed. On the south side, the fan-like diffluence of the ice occurred partly in the Alps, and was really restricted to it in the region of the lakes north of Milan, which we will call Insubrian lakes after the ancient country of the Insubrii, whose capital was Milan.

Everywhere where a fan-like diffluence of the ice occurred its bed shows ramifications which have a spoke-like arrangement and slope toward their center. Thus, for example, in the fan of the old Rhine glacier. Lake Constance is the center of the fan, its western termination bifurcating into lakes Uberlingen and Zell. In two similar broad furrows, the rivers Schussen and Argen approach the lake from the north and northeast. Lake Constance is the palm of the hand, its western branches and the furrows of Argen and Schussen being fingers which stretch out to the rim of the old glacier. A similar arrangement is found in the fans of the old glaciers of the Inn and the Salzach, the trough of the valleys terminating by branching in the sub-Alpine plains; and every branch is followed by a river flowing toward the Alps, in the direction from which the ice came, thus marking the reversed slope of the bottom of the different branches of the ice which formed the ice-fan. The same features reoccur where the diffluence of the glacier took place in the mountains. Lake Como bifurcates, and the Como branch has no outlet. Its waters must first flow toward the Alps to reach the outlet at Lecco. On the east side of Lake Como a branch of the old Adda glacier penetrated into the Valsassina, whose waters flow toward the Alps in order to reach Lake Como, revealing a reversed slope. A fourth finger of the Adda

glacier passed over the Pass of Porlezza and reached the eastern deep part of Lake Lugano, which drains into Lake Maggiore. If the morainic deposits to the south of the eastern part of Lake Lugano were higher, that lake would discharge into Lake Como, and the relation of the eastern part of Lake Lugano to Lake Como would become very clear. It is also a finger-lake, lying around the palm-lake of Lake Como, but separated from it by a low pass.

The finger-lakes and finger-valleys, with their reversed drainage, are a very conspicuous feature in the regions of glacial diffluence. Many phenomena indicate that they were not originally there, and that their formation was connected with the diffluence of the glaciers. Lake Orta is a typical finger-lake in the region of diffluence of the old glacier of the Ticino, and has a reversed drainage. It occupies, however, a valley whose catchment basin has a peculiar arrangement, as if it would be drained toward the Po plain. It can be shown that the Lecco branch of Lake Como came very lately into use as an outlet for a branch of the Adda glacier. It can be further determined that the different fingers in the large fans of the glaciers on the north side of the Alps are younger than the gravels of the first glacial epoch. How glacial diffluence controls the formation of these features can be shown by the study of those forms which are originated by it.

When a glacier fills a valley above the height of the notches in its watershed, it flows over these notches, if it is not hindered by ice masses on the other side of the pass. By overflowing, it exercises on the pass a conspicuous erosive action, by which the pass is lowered and widened. This can be seen in all passes which have been overflowed by ice. On the St. Gotthard and on the Grimsel, ice-marks are very clear, *roches moutonnées* with their scour and pluck sides spread over the culminating surface, and little mountain tarns indicate that the glacier eroded flat basins. The longer the ice-action goes on, the more the pass is lowered; the height of the watershed is leveled down to the floor of the valley, into which the glacier pours, and a vast flat is formed which begins at the shoulders of the valleys from which the ice branched. Many Alpine passes belong to this type. They can be reached from the glacier valley only by a sharp ascent on its trough-side, while the descent into the neighboring

valley is very slow. This is the case with the Monte Ceneri, which opens in the left side of the valley of the Ticino, and allows one to enter the surroundings of Lugano from the north; with the Pass of Seefeld, through which you reach the valley of the Inn south of Munich; and with the famous Pass of Reschenscheideck, through which you pass from the lower Engadine to the headwaters of the Adige. The erosion of this pass was carried so far that the floor of the pass reaches the shoulder of the Engadine, and that some old affluents of the Inn were already diverted into the Adige. A further state of erosion of an old pass is shown by the situation of Lake Orta. Here the pass has been totally leveled down, and considerable accumulations of moraines south of it force its water northward toward the Alps. Finally, in Valsassina, the long-reversed slope is independent of the terminal moraines south of it. It is a branch of the trough of the Adda valley, which extends here into a side valley where it terminates obtusely. This series of different stages shows us how the watersheds can be moved to the outer rim of the old glaciation. This state, however, has not been reached elsewhere. Its establishment depends not only on the intensity of glacial action, but also upon the original features. A pass originally very high will stand far longer than a low one. This fact must be observed in those cases where the valley, reached by a branch of the ice, is overdeepened in a way similar to the main valley. Thus, for example, that branch which branched off the glacier of the Ticino valley at the Monte Ceneri overdeepened the valleys west of Lugano, which are now occupied by the west branch of Lake Lugano, and the branch of the Adda glacier, which branched off at Menaggio, and passed the saddle of Porlezza, has overdeepened the valley of Porlezza and transformed it into the lake basin of Porlezza, which is the deepest part of Lake Lugano. He who considers only the lake basins as the results of glacial erosion will be much puzzled by the interruption of the erosive action of a glacier by a pass. On the other hand, he who follows the whole development of glacial erosion will easily recognize its great effect also on the pass traversed by the ice, and he will perhaps be aware that the erosion on the pass itself was more considerable than that which formed a basin.

The diffluence of the ice is controlled by the rule of cross-sections,

as is the confluence. In the same way, as steps were formed at the places where glaciers met, other steps occur where branches occurred, for here there was a sudden diminution of the ice. There are steps of confluence in the region of confluence, and steps of diffluence in the region of diffluence. The steps of confluence are seen in the hanging mouths of side valleys; the steps of diffluence are hanging openings of those valleys which were entered by a branch of the ice. The height of both kinds of steps will generally be more considerable, the greater the difference between the main glacier and its affluent or diverting branch. Thus the step of diffluence of Valsassina east of Lake Como is higher than that of Porlezza west of this lake, and the branches of Como and Lecco divided at about the same level, since they were of nearly equal size. Here is a true bifurcation of branches, and a bifurcation of valleys follows the diffluence of the ice, if the openings of the neighboring valleys passed by the ice are so deeply eroded that they will be easily buried by the accumulation of river material which is being deposited in all overdeepened valleys since they were vacated by the ice. The bifurcation of the Rhine valley near Sargans, that of the Isère valley at Montmélian, and that of the Salzach valley near Zell am See are fine samples of valley bifurcation caused by glacial diffluence, and not, as often said, by capturing.

The establishment of a reversed drainage in consequence of glacial diffluence is very much helped by the accumulation of moraines. They surround the dissipating part of the glacier. They follow its sides as lateral moraines and surround its end as frontal moraines. In the glacier fans north of the Alps they form conspicuous landscapes. They are often watersheds between the reversed drainage of the fan and the drainage of its surroundings, which corresponds to the drainage of the ice-fan during its existence. Thus, for example, the terminal moraines of the Rhine glacier form part of the great European watershed between the northern seas and the Mediterranean. On the south side of the Alps the terminal moraines are still more conspicuous, and form amphitheaters around the ends of the overdeepened glacier beds. These are the so-called morainic amphitheaters of upper Italy, whose deposits partially dam up the Italian lakes. Those glaciers which ended in the Alps left their

terminal moraines in the valleys, where they separate the reversed drainage in the region of diffluence from a peripheral drainage. The latter has been partially formed by shoving away the original rivers which descended to the ground before it was entered by the glaciers. When the ice came, they could not continue their courses and must flow along its rim. Thus they were pushed from their old courses and driven into new ones, which surround the ends of the glaciers. Many of these shoved river courses are no longer in use, having often been captured by the headwaters of the reversed drainage, as, for example, the Mangfall in Bavaria, which for a long distance flows along the terminal moraines of the Inn glacier, until it makes an elbow at the place where it was captured by a stream flowing on a reversed slope. Other shoved river courses became stable, since they were driven into the valleys of other rivers. Thus north of the old glacier of the Dran the waters of the upper valley of the Gurk were shoved by the rim of the ice into that valley which is now that of the middle Gurk, and which formerly had its own river. Here the moraine of the glacier along which the Gurk was shoved is still visible. In other cases the moraines are insignificant, especially where the glacier ended in a deep valley, and the course of shoved rivers can be traced only by the erosive action exercised along the glacier, cutting gorges into the projecting parts of the valley side. A magnificent example of such a shoved river can be followed on the left slope of the valley of the Sesia in upper Italy below Varallo. By their erosion on mountain passes, by establishing reversed slopes in their terminal regions, and by shoving the rivers coming from non-glaciated regions, the old glaciers of the Alps have profoundly modified, especially near their ends, the preglacial hydrography of the Alps.

The traces of glacial action in the Alpine valleys extend beyond the limits of the trough. Near the ends of the ancient glaciers the troughs are overlooked by moraines, which now and then are located directly on the shoulders. In the interior of the mountains the striated and rounded surfaces reach far above the shoulders, and there is a very marked scoring limit which separates those parts of the valley slopes which have been buried under the ice and rounded by it, from the higher, ragged slopes, which suffered by weathering. The

chamfer at the scoring limit (*Schliffkehle*) exhibits clearly a sapping action of the ice exercised along its sides, and this lateral erosion seems to have been strongest near the surface of the glacier. This condition is perhaps caused by the more brittle state of the glacier ice near its surface, while the trough indicates that the glaciers eroded intensively downward at their bottoms.

Glaciers not only exercise a sapping action along their sides, but also at their very heads, if they are here overlooked by rock cliffs. There is always a marginal crevasse, called in German *Randspalte* or *Bergschrund*, which separates the moving ice from the rocks which overlook it. The material loosened here by weathering falls down from the rock walls into this crevasse and arrives at the bottom of the névé, where it is pushed forward by the moving mass grinding the bottom of the glacier. By this, not only the formation of screes around the glacier is hindered, but also the surrounding cliffs are constantly attacked, for the erosive action begins just at their foot and saps them. Glaciers, therefore, which are formed on slopes in broadly open valley basins, surround themselves finally by cliffs, which are pushed backward much as are the cliffs around the gathering basin of a torrent. The bottoms of hanging glaciers may be transformd much as are the floors of main valleys which are occupied by glaciers. The rule of the cross-sections is equally applicable to them. A glacier, for example, which ends on the slope can erode the central parts of its bed below the level of its lower end and thereby establish reversed slopes. Thus the original broadly opened valley basin will be gradually changed into a sharply limited niche with a basin on its bottom. The cirquelike form originating in this way is the *Kar* or "corrie." It differs essentially from that cirque which forms the end of a valley trough, though there is often much similarity in their mere appearance. The trough's end is formed in the bed of a glacier; the corrie at the head of the glacier. The ice moves down over the cliffs of a trough's end, while it moves away from the cliff of a corrie. After having climbed over the walls of the trough's end, one arrives at a flat, formerly occupied by a hanging glacier usually surrounded by cliffs. Then one arrives at a corrie or a series of corries. An ascent of the walls of a corrie always leads one to the crest of mountains. Therefore we distin-

guish between cirques in valleys and cirques on slopes, between trough's ends and corries.

The forms produced by small glaciers on the slopes of the valleys vary very much. One feature is produced everywhere where the glaciers are overlooked by rocks; that is, the corrie cliff, originated by sapping. The formation of a basin at the foot of these cliffs depends on the same conditions as the formation of a basin in a valley occupied by a glacier; it is only formed where the successive cross-sections, after having increased, again, diminish—a condition which is regularly found in those glaciers which end on the slope on which they began. The true corries, with basins in their bottoms, are therefore mostly the beds of isolated hanging glaciers which did not descend far below the snow limit, and their bottoms lie nearly at the level of this limit. But if on the slopes we have glaciers which feed the valley glaciers, then we have usually to deal only with an increase of their cross-sections, and their bottoms descend without interruption somewhat below the surface of the valley glaciers. Then an *open corrie* is formed, the bottom of which often terminates rather abruptly a little below the scoring limit along the sides of the glacier valley. There are many transitions between the true, closed corrie and the open corrie; for there are many transitions between isolated hanging glaciers and affluent hanging glaciers. Now and then we find closed corries along the sides of a valley glacier, formed by its lateral affluents, which were dammed up by it. On the other hand, we find open corries as the beds of local, isolated glaciers, which lay on slopes the steepness of which was not favorable to the establishment of reversed slopes.

Closed corries prevail in the eastern parts of the Alps, where this mountain chain did not reach far above the snow-line of the Great Ice Age. Now and then we find here mountains with a single corrie or *Kar*, whose steep cliffs contrast strongly with the rounded and smoothed forms prevailing around it. Other summits are rather crowded with corries, which have eaten back so far that there is only a part of the old rounded mountain surface conserved. In other cases the last trace of the latter has disappeared, and there is a sharp crest line which separates the corries or *Kare* of opposite sides. If this crest disappears under the attacks of the glaciers, then a flat surface

will be formed in the place of a former dome-shaped elevation. This surface will, however, not reach below the snow limit. Thus by the action of isolated hanging glaciers mountain summits may be degraded nearly to the level of main glaciers, so far as they lie above the snow-line.

Open corries prevail in the highest parts of the Alps, in Tyrol and in Switzerland. Their forms vary according to the height of the valley slopes above the level of the main valley glaciers. The higher these slopes are, the steeper they become, and the steeper then the slope of the bottom of the corrie. The steeper this slope, the smaller becomes the angle between it and the surrounding cliffs, and in those parts of the western Alps which reached highest above the surfaces of the neighboring valley glaciers the cliffs and the steep bottoms of the open corries nearly unite, to form very steep cliffs, the feet of which are and were constantly attacked by steep hanging glaciers formed by snow avalanches and interspersed with stones which have fallen down. The cliffs of two opposite glaciers of this kind usually intersect at a very acute angle, and form very sharp ridges whose summits are needle-like. These are the features in the Mont Blanc region, with its *aiguilles*. The height of all these sharp crests is determined by their elevation above the neighboring valley glaciers. Neighboring crests have, therefore, nearly uniform heights, and all rise in height in that direction from which the ice radiates or radiated. Therefore, seen from a distance, the centers of glaciation of the Great Ice Age, which are still today the scenes of a very strongly developed glaciation, appear as extended domes, which are very much dissected by glaciated valleys, and from which rise only a few isolated peaks, in places where the rocks resisted best the attacks of weathering. The Mätterhorn and the Gross-Glockner are types of these horns of highest resistance. They show clearly that the actual height of the sharp mountain crests of the Alps is far from being an original one. It is determined by destructive processes, the attacks of which still go on above the actual glaciers, constantly lowering the crests and the summits. The latter fact leads to the conclusion that our process of destruction is a rather modern one, for if it had lasted for a longer time, it would long ago have removed the whole of those crests projecting above the glaciers. It was believed that the crests of the

mountains had been protected during the Great Ice Age by a covering of snow, and that the destruction has since begun. But the fact that the surfaces of the old glaciers served as a base-level of destruction, as the surfaces of actual glaciers do, leaves no doubt that also in the glacial period the destructive process went on. Its youth must, therefore, result from other causes, as has been believed until now. There are many reasons for assuming that the Alps were elevated during the Great Ice Age, and that this elevation was a true vertical upheaval. The youth of the high mountain crests might be caused by such a recent upheaval, still going on.

That the surfaces of the valley glaciers serve as a base-level of destruction for the hanging glaciers is a fact which corresponds to the same relation between the surfaces of side and main rivers. The other fact, that also the snow-line is such a level, helps us to understand the relation between the rates of glacial and fluviatile erosion. The snow-line becomes visible in the forms of those mountains which rise above the snow-line of the glacial period in such a way as to show that above it the destruction of the mountains went on more quickly than farther down. The sudden increase of the destruction of mountains cannot be directly caused by a sudden climatic change between the elevations below and those above that line, causing a difference of weathering. We know there is such a gradual transition of the climate in the neighborhood of the snowline, that it is very difficult to recognize the climatic features determining its position. The increase of destruction above the glacial snow-line is not due to an increase of weathering above it but is caused by the development, of a new agency, degrading land at a faster rate than the running water. This agency is the glacier ice.

Ice does not protect its bottom, as commonly believed; it attacks vigorously. These attacks become most visible where glaciated surfaces extend into the neighborhood of non-glaciated areas. There we have a continual sapping of the latter. They cannot be as easily recognized on surfaces which were totally covered with ice, for these suffer by a general degradation. Therefore mountains which have been totally covered with ice will not exhibit the same features as those which had only local glaciers. They will have no corries, and they will conserve, under their covering of ice their rounded surface;

but this will be degraded and everywhere lowered. Thus we see, besides those mountains into which closed and opened *Kare* have been gnawed, others which projected equally above the glacial snow-line, which still conserve more or less completely their preglacially rounded forms. They were totally buried under the ice.

The actual surface features of the Alps do not at all correspond to those of a water-worn mountain range. Their conformation is mostly due to ice-action, which becomes most visible where the old glaciation ceased. It shows an adjustment to ice-action which is not quite perfect everywhere, since it probably has been disturbed by earth-movement in its highest parts, and by the action of the receding ice during its oscillations in postglacial time. These oscillations have led to the deposition of morainic material at places where erosion had before been active, and to the increase of erosion at other places. They have only slightly modified the general features worked out during maximum glaciation. We must conclude, therefore, that the durations of the maxima of glaciations, surpassed considerably the times of the increase and recession of glaciation, that is, the pre-glacial and postglacial times.

NOTES ON SOME CARBONIFEROUS COCHLIODONTS WITH DESCRIPTIONS OF SEVEN NEW SPECIES

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The following article is the result of the writer's study of the teeth of the genera *Cochliodus*, *Psephodus*, *Sandalodus*, and *Deltodus*, in the collection of Walker Museum at the University of Chicago. In the collection are several hundred specimens of the teeth of *Sandalodus* and *Deltodus*, and more than fifty of *Cochliodus* and *Psephodus*.

The writer is under obligation to Dr. Stuart Weller for the privilege of studying the collection at Walker Museum, and to Professor C. E. McClung for the loan of specimens from the Kansas University Museum. Acknowledgment is due Professor S. W. Williston and Dr. Stuart Weller for helpful suggestions during the investigation.

Psephodus Agassiz

Cochliodus Agassiz, 1838 (*Recherches Poissons fossiles*, Vol. III, p. 174).
Cochliodus Portlock, 1843 (*Geological Report on Londonderry*, Plate XIV, Fig. 4).
Cochliodus McCoy, 1855 (*British Paleozoic Fossils*, p. 622).
Psephodus Agassiz, 1859 (MSS in the Enniskillen Collection).
Psephodus Morris and Roberts, 1862 (*Quarterly Journal of the Geological Society*, Vol. XVIII, p. 101).
Aspidodus Newberry and Worthen, 1866 (*Paleontology of Illinois*, Vol. II, p. 92).
Taeniodus St. John and Worthen, 1883 (*ibid.*, Vol. VII, p. 75).

A jaw of *Psephodus* with four teeth in place is preserved in Walker Museum at the University of Chicago. The full dentition of the jaw is probably not present, the front teeth having their anterior margins thick and truncated, as for articulation with other teeth. The missing anterior teeth were probably triangular in form and considerably smaller than those with which they articulate, but no place remains on the jaw for the helodoid teeth which have been so generally considered as forming a component part of the dentition of this genus.

The history of the belief in the association of helodoid teeth with the large plates on the jaw of *Psephodus* is interesting and is briefly sketched below.

The earliest mention of this supposed association is in a letter written by Captain Jones to Portlock, and published in 1843,[1] in which he says: "I think I am enabled to show that, however distinct and well marked the extremes may be, yet *Helodus planus* passes into *Cochliodus magnus*." In connection with this statement no evidence is given for its support. In publishing the results of his investigations on the arrangement of *Psephodus* teeth, Davis says in summary:

> That a row of three principal teeth increasing in size backward were attached to each cartilaginous ramus of the jaw; that the diameter of the jaw, as indicated by the groove or channel on the under surface of the teeth, diminished toward the symphysis; that a long narrow tooth was placed in front of the anterior one; and that a series of at least three helodoid teeth were placed behind it extending over the palate and increasing in size backward.[2]

The same year St. John and Worthen published the results of their studies on this genus and described an entirely different arrangement of the teeth. They conclude that—

> While the median portion of the rami of the jaw of *Psephodus* was enveloped by a moderately contorted dental plate, constituting its chief point of resemblance to *Cochliodus*, this plate was flanked on either side by a series of teeth disposed in rows from within outward similar to the occurrence of the teeth in the jaws of *Cestracion*. Therefore the solid triturating plates of *Psephodus* are not strictly homologous with the large posterior teeth of *Cochliodus*, but they are more properly designated as median teeth of the rami of the jaws[3]

In 1885 Traquair published his conclusions as to the arrangement of *Psephodus* teeth, saying:

> On the whole, I consider that view most likely to be correct which would ascribe to the mouth of *Psephodus* four large tooth plates, two above and two below, each occupying on the ramus a position similar to that of the row of the largest teeth of *Cestracion*, or of the so-called median teeth of *Cochliodus*, but that of the upper jaw differing slightly in form from the one opposed to it below. . . . . Teeth of different forms seem to have been present in the jaw, external to and in front of the large plate; those in its immediate vicinity belonging more or less to the category of *Helodus planus*. . . . . But the front of the jaw was armed

[1] Portlock, *Geological Report on Londonderry* (1843), p. 462.

[2] *Scientific Transactions of the Royal Dublin Society*, Vol. I (1883), p. 417, Plate LV, Figs. 1–4.

[3] St. John and Worthen, *Paleontology of Illinois*, Vol. VII (1883), p. 64.

with small teeth belonging to the type which has been designated as *Lophodus* by Romanowski, and the forms *didymus* and *laevissimus*, both named as species of *Helodus* by Agassiz.[1]

During the progress of the present investigation a study of a portion of the types of *Psephodus crenulatus* and *P. obliquus*, in addition to the specimen already mentioned with the teeth in position, and described in this paper as *Psephodus legrandensis*, has led to the following conclusions: The teeth called median mandibular by St. John and Worthen[2] are posterior and correspond to the posterior teeth of *Cochliodus*. The teeth called median maxillary by the same authors are median, but not in the sense that they used the term. They articulate behind with the large posterior plates and in front with the small anterior teeth, and do not articulate with helodoid teeth, as St. John and Worthen thought. In this genus there is nothing that enables us to distinguish the maxillary from the mandibular teeth. Teeth like those called mandibular by St. John and Worthen have been found in place on the same jaw with those called maxillary. (See Plate I, Fig. 2.) All of the teeth of *Psephodus* that have been described belong in the categories hitherto known as median mandibular and median maxillary teeth, and, as before said, they occur on the same jaw.

In previous publications the commonly expressed opinion has been that helodoid teeth were present on the same jaw with the large grinding plates of *Psephodus*, although very little evidence in support of this has been forthcoming. The only evidence that seems to be of much weight in its support is that furnished by a specimen described by Traquair in 1885.[3] In this specimen forty-four helodoid teeth are preserved on the same slab with two of the large *Psephodus* teeth. It is no uncommon occurrence for teeth of different species to be preserved in close association, and the mere fact of such an association proves nothing, although, so long as no evidence to the contrary was forthcoming, it might well suggest the possibility that all the associated teeth belonged originally in the same jaw. Traquair's interpretation of the original position of these teeth in

[1] Traquair, *Geological Magazine*, 1885, p. 343.

[2] *Paleontology of Illinois*, Vol. VII, Plate I, Figs. 1 and 2, pp. 66 and 67.

[3] *Geological Magazine*, 1885, pp. 337–44.

the jaw from their present positions on the slab shows that they are badly disarranged and might easily come from two or more specimens. He says[1] that of the two large teeth one belongs to the form called by Davis posterior, and the other to the form called median, but that they are not associated in such a way as to lend any support to that author's theory as to their arrangement. But the specimen of *P. legrandensis* furnishes positive evidence that Davis' theory in regard to the linear arrangement of the teeth is correct, with certain modifications. Only two large teeth are present in Traquair's specimen, while at least eight are necessary for the full dentition of both jaws. The teeth are so associated that Traquair concludes that the large plates occupied a position on the ramus similar to that of the median teeth of *Cochliodus*, and that helodoid teeth were arranged in front and external to them; but the specimen of *Psephodus legrandensis* before mentioned shows that such was not the position of the large plates, and that helodoid teeth could not have occupied the supposed place with reference to them.

Although the linear arrangement of the teeth of *Psephodus* postulated by Davis is in part correct, the inner margins of the teeth are placed outward in his restoration, as has been pointed out by Traquair,[2] and a glance at the dentition of *P. legrandensis* (Plate I, Fig. 2) shows that there was no place on the jaw for helodoid teeth. On each ramus of the jaw one large posterior tooth, one median tooth, usually much smaller, but in some species nearly as large as the posterior tooth, and probably one small triangular anterior tooth, are present. But instead of the teeth being arranged in a semicircle, as Davis supposed, those of the two rami touch or approach each other very closely along the median line of the long axis of the jaw.

A comparison of the dentition of *Psephodus*, as shown in *P. legrandensis*, with that of *Cochliodus* brings out certain striking similarities. The arrangement of the large *Cochliodus* teeth is similar to that of *Psephodus*, the principal difference being that they do not meet along the median line, as in *Psephodus*, but spread apart, leaving a V-shaped area. The specimen from which Newberry and Worthen drew their conclusion that helodoid teeth were associated

[1] *Ibid.*, p. 342. [2] *Ibid.*, p. 342.

on the same jaw with *Cochliodus* teeth furnishes little evidence to support that hypothesis. The teeth are not in position, and they have the appearance of having been accidentally associated. Owen has shown[1] almost beyond question that *Cochliodus* had only three teeth on each ramus of the jaw, and more evidence than a few *Helodus* teeth found preserved in close association with *Cochliodus* teeth is necessary to demonstrate that they belonged in the same mouth. Thus it seems probable that in *Cochliodus* as well as in *Psephodus* no helodoid teeth were present in the dentition.

Psephodus legrandensis *sp. nov.*

(Plate I, Fig. 2)

A small species. Median tooth 5^{mm} broad, 8^{mm} along inner margin, 5^{mm} along outer margin. Inner posterior angle acute and produced backward; outer posterior angle obtuse, rectangular on both sides in front. Tooth strongly enrolled transversely, not arched longitudinally. Inner margins of the two median teeth parallel to each other when in position on the jaw, and approaching very closely on the median line. Posterior teeth subpentagonal in outline, 11^{mm} from posterior inner angle to anterior angle of outer edge, 6^{mm} along articular edge in median line, 8^{mm} along articular edge for anterior tooth. Teeth strongly arched longitudinally, little arched transversely, not ridged or furrowed. Enamel everywhere finely punctate. Edges not crenulate.

The posterior teeth of this species are readily distinguished from *P. crenulatus*, *P. obliquus*, and *P. placenta* by their smaller size, comparative narrowness, and greater longitudinal arching. The median teeth are more strongly enrolled transversely and proportionately narrower than those of the species above mentioned. The median teeth are distinguished from those of *P. acutus* by their smaller size, greater enrollment and the posterior angle being much less produced.

Formation and locality: Kinderhook limestone; Legrand, Iowa.
Paleontological Collection, Walker Museum, No. 10038.

Psephodus acutus *sp. nov.*

(Plate I, Fig. 1)

Type and only specimen observed a median tooth. Measurements: 10^{mm} along the inner margin, 5^{mm} along the outer margin, 7^{mm} along the posterior articular edge, 6^{mm} along the anterior articular edge. Tooth not arched longitudinally, considerably enrolled transversely. Outer and inner margins parallel.

[1] *Geological Magazine*, 1867, pp. 59–63.

P. acutus differs from *P. legrandensis* in the posterior inner angle being much more produced, in being less enrolled transversely, in its greater breadth, and in the anterior and inner margins meeting in a slightly more acute angle. The species is a little larger than *P. legrandensis*. The surface of the enamel is everywhere finely punctate.

Formation and locality: Coal Measures; LaSalle, Illinois.
Paleontological Collection, Walker Museum, No. 10036.

Psephodus carbonarius *sp. nov.*

(Plate I, Fig. 7)

Type and only specimen observed, a posterior tooth. Measurements: antero-lateral margin, 20^{mm}; postero-lateral margin, 18^{mm}; greatest breadth, 19^{mm}. Tooth thin, strongly arched transversely and longitudinally. Trapezoidal, with antero- and postero-lateral borders about the same length. Tooth highest near the anterior angle of the postero-lateral border. From this high point the surface declines abruptly to the anterior angle of the postero-lateral border and slopes down gradually to the other borders. Surface of enamel everywhere finely punctate. Lines of growth faintly impressed or absent. Margin not crenulate.

P. carbonarius is readily distinguished from *P. crenulatus* by being much more strongly arched and lacking crenulations.

Formation and locality: Coal Measures; Newport, Indiana.
Paleontologic Collection, Walker Museum, No. 10032.

Deltodus and **Sandalodus** Newberry and Worthen

That the genus *Sandalodus* has not been sufficiently well defined to separate it from *Deltodus* is shown by the disagreement among authors concerning the genus to which the species *Deltodus grandis* and *D. complanatus* should be assigned. Newberry, who described[1] both genera, says[2] that *D. grandis* is a typical *Deltodus*, while St. John and Worthen[3] and Eastman[4] believe that it is a *Sandalodus*. Newberry contends that *D. complanatus* is a typical *Deltodus*,[5] while St. John and Worthen[6] and Eastman[7] call it a *Sandalodus*.

During the progress of the present investigation several hundred

[1] *Paleontology of Illinois*, Vol. II, pp. 95 and 102.

[2] *Transactions of the New York Academy of Science*, 1897, pp. 297 and 209.

[3] *Paleontology of Illinois*, Vol. VII, p. 184.

[4] *Bulletin of the Museum of Comparative Zoölogy*, Vol. XXXIX, p. 198.

[5] *Op. cit.*, p. 102. [6] *Op. cit.*, p. 184. [7] *Op. cit.*, p. 198.

specimens of the teeth of *Sandalodus* and *Deltodus* have been studied, and one fundamental difference, perhaps of family rank, seems to distinguish one genus from the other. This difference is in the number of teeth to each ramus of the jaw, *Sandalodus* having only one tooth to each ramus and *Deltodus* having three. Only the actual finding of the teeth in place can prove this conclusion beyond all question, but the evidence in hand makes it seem more than probable. In all cochliodonts, whose full dentition is known to have more than one tooth upon each ramus of the jaw, the posterior teeth have their antero-lateral margins modified for articulation with other teeth. The teeth of *Sandalodus* have no articular edge and show no sign of other teeth having been in contact with them. No teeth of proper shape and size to fit the large plates of *Sandalodus* have been observed during the present investigation. St. John and Worthen figure and describe[1] what they call median mandibular teeth of *Sandalodus laevissimus*, but, judging from the figures, the teeth are far too much enrolled to fit the large plates of *S. laevissimus*. Furthermore, if anterior teeth were present, they should be preserved in as great abundance as the so-called posterior teeth, but, aside from those figured by St. John and Worthen, none of the kind are known, while the posterior teeth are rather common. In the Burlington limestone, where the teeth of *Deltodus spatulatus* and *Sandalodus occidentalis* are about equally common, the anterior teeth of *D. spatulatus* are numerous, though usually fragmentary; but no teeth that fit the large plates of *S. occidentalis* have been found. In regard to the dentition of *Sandalodus*, Davis says: "It does not appear probable that there was more than one tooth to each ramus of the jaw."[2] Davis believes that the mandibular teeth of *Sandalodus* differ considerably from the maxillary teeth, but in a study of all the specimens of this genus in Walker Museum it has proved impossible to distinguish mandibular from maxillary teeth, and this is true also of *Deltodus*.

There can be little doubt that *Deltodus* had three teeth on each ramus of the jaw. Owen has shown[3] that in the complete dentition

[1] *Op. cit.*, Vol. VII, p. 166, Plate XII, Figs. 8 and 9.

[2] *Scientific Transactions of Royal Dublin Society*, Vol. I (1883), Series III, p. 436.

[3] *Geological Magazine*, Vol. IV (1867), p. 60, Plates III and IV.

of the closely allied genus, *Cochliodus*, three teeth were present on each ramus, and it has already been shown in this paper that the same is true of *Psephodus*. Davis figures one specimen of *Deltodus* dentition with two teeth in position on one ramus.[1] In discussing this specimen he says:[2]

> Connected with the posterior tooth a second one, hitherto regarded as a separate species under the name *Poecilodus parallelus*, has been found, which leaves no room to doubt that it is in its natural position, and from the character of its inside margin leads to the natural inference that a third tooth occupied the front or median portion of the lower jaw.

In all median teeth of *Deltodus* that are known the anterior edge is truncate or grooved, as if for articulation with other teeth.

Eastman says[3] that analogy of *Deltodus* with *Cochliodus*

> leads us to expect, in advance of the anterior dental plate, a series of helodus-like teeth above and below, and in front of this, at the symphysis of at least one jaw, a series of bilaterally symmetrical teeth, arched in a single plain, and corresponding to the form described by Newberry as *Helodus coxanus*.

No specimen of *Deltodus* furnishing any evidence in proof of this is known, and if, as it seems most probable, *Cochliodus* had no helodus-like teeth, there is nothing left to support such a hypothesis as to the dentition of *Deltodus*.

Sandalodus occidentalis Leidy

(Plate I, Figs. 8 and 9)

Cochliodus occidentalis Leidy, 1857 (*Transactions of the American Philosophical Society* (2), Vol. XI, p. 88, Plate V, Figs. 3–16).

Deltodus stellatus Newberry and Worthen, 1866 (*Paleontology of Illinois*. Vol. II, p. 97, Plate IX, Fig. 2 [not Fig. 3]).

Deltodus complanatus Newberry and Worthen, 1866 (*ibid.*, p. 98, Plate IX, Fig. 4).

Deltodus complanatus Newberry and Worthen, 1870 (*ibid.*, Vol. IV, Plate III, Figs. 5, 8, and 12).

Deltodus occidentalis St. John and Worthen, 1883 (*ibid.*, Vol. VII, p. 150, Plate IX, Fig. 9 [not Fig. 10]).

Deltodus intermedius St. John and Worthen, 1883 (*ibid.*, p. 153, Plate IX, Figs. 14 and 15).

Sandalodus complanatus St. John and Worthen, 1883 (*ibid.*, Vol. VII, p. 184, Plate XII, Figs. 1–4).

[1] *Op. cit.*, Series II, Plate 52, Fig. 9. [2] *Ibid.*, p. 430.

[3] *Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, p. 200.

Deltodus complanatus Newberry, 1897 (*Transactions of the New York Academy of Science*, Vol. XVI, p. 298, Plate XXIV, Figs. 1–7).

Deltodus occidentalis Eastman, 1903 (*Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, p. 200, Plate 4, Fig. 38, and Plate 5, Fig. 53).

Sandalodus complanatus Eastman, 1903 (*ibid.*, p. 198).

Teeth triangular in outline. In teeth of average size, 40–60^{mm} long, postero-lateral border about 1^{cm} longer than antero-lateral. The outer end terminates in an acute point; the inner end has the inner angle obtuse, the outer angle acute. Tooth slightly arched longitudinally and transversely, but, as compared with associated species, flat and thin. A low, broad ridge extends from the obtuse angle of the inner end to the outer end. From this ridge the surface declines very rapidly to the thin antero-lateral border and gently toward the postero-lateral border. Alation broad, slightly upturned. Enameled surface smooth and polished, everywhere finely punctate. Lines of growth usually not well marked. Antero-lateral border not modified for articulation with other teeth, usually straight or slightly convex.

S. occidentalis differs from *D. spatulatus* in being much less arched both longitudinally and transversely, and in having the ridge, which is not as high as in *D. spatulatus* extending from the obtuse angle to the outer end very close to the antero-lateral edge, instead of at some distance from it, as in *D. spatulatus*. The surface of the tooth declines rapidly to the antero-lateral border from the top of the ridge, and gently toward the postero-lateral border, while in *D. spatulatus* the stronger slope is toward the postero-lateral border. Antero-lateral margin not concave, as it is in *D. spatulatus*.

This species is referred to *Sandalodus* because there is evidently only one tooth to each ramus of the jaw. As has been stated, the large teeth have no articular edge, and although they are numerous in the Burlington limestone, no teeth have been found that could occupy the position of the median or anterior teeth as present in the dentition of *Deltodus*, *Cochliodus*, and *Psephodus*.

In examining a large number of fragmentary teeth of *Sandalodus complanatus* and *Deltodus occidentalis*, it was found impossible to distinguish one species from the other, and, after examining more than a hundred well-preserved teeth, the conclusion was reached that the two groups of teeth represented a single species. In large collections they grade into each other to such an extent that it is impossible to separate them, but it is not difficult to understand

how they came to be described as two distinct species from scanty material.

Eastman says[1] he is convinced that "the teeth figured as *Deltodus complanatus* in the posthumous paper of Newberry are fragments of *D. occidentalis*." These specimens are now preserved in the collection of Walker Museum, and as two of them are practically complete, there is no reason why Newberry should have identified them incorrectly, and with the union of the two species both Newberry and Eastman are correct in their conclusions.

Formation and locality: Kinderhook, Burlington, and Keokuk limestones; Iowa, Illinois, and Indiana.

Sandalodus emarginatus *sp. nov.*

(Plate II, Figs. 1, 2 and 3)

A very large species. The dimensions of the type specimen are: 95^{mm} along the antero-lateral border, 65^{mm} along the inner end, 110^{mm} along the postero-lateral border, 26^{mm} in thickness at the thickest part. Strongly arched longitudinally and transversely. Alation strong, extending out 40^{mm} from the postero-lateral border. At the place where this alation diverges from the main part of the tooth there is a strong notch which extends to the middle of the alation in a line parallel with the main axis of the tooth. The anterior border of the alation is gently convex to near the outer angle, where it is strongly convex. The alation is thick and strong, does not turn up at the outer angle, and has a sharp ridge extending from the outer angle to the middle of its base, the sharpness of this ridge being due to the worn condition of the tooth near the inner border. Rings of growth show faintly on this worn surface. Inner end of tooth gently convex near the antero-lateral border, gently concave near the postero-lateral border. Inner posterior angle slightly obtuse. Outer end curved abruptly downward, and probably wound once and a half on itself as in *Sandalodus laevissimus*.

S. emarginatus differs from *S. laevissimus* in being more strongly arched both transversely and longitudinally, in being thicker and stronger, in having a strong notch where the alation diverges from the main part of the tooth, and in the alation being thick, convex upward, and not turning up at the point:

The types of *S. emarginatus* are two specimens, one of which is almost perfect, only a small part of the initial coil being absent; the other has lost part of the initial coil and half of the alation.

Formation and locality: Keokuk limestone; Keokuk, Iowa.
Paleontological Collection, Walker Museum, No. 10059.

[1] *Op. cit.*, 1903, p. 198.

Sandalodus alatus Newberry and Worthen

(Plate I, Figs. 3–5)

Deltodus alatus Newberry and Worthen, 1870 (*Paleontology of Illinois*, Vol. IV, Plate II, Fig. 6, p. 368).

Deltodus alatus Woodward, 1889 (*Catalogue of Fossil Fishes in British Museum*, Part I, p. 199).

Deltodus spatulatus Eastman, 1903 (*Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, p. 198).

In a paper published in 1903 (*loc. cit.*, p. 198) Eastman gives *Deltodus alatus* as a synonym of *D. spatulatus*. The specimens of *D. alatus* teeth in the collection of Walker Museum are all more or less fragmentary, but they present the following characters which serve to distinguish them from *D. spatulatus*. The pores in the enamel are much larger and fewer in number. The average number per square millimeter being four in *D. alatus* and seven in *S. spatulatus*. The postero-lateral border of *D. alatus* teeth has a broad, thin alation extending its full length. Near the outer end this alation is much broader than the accompanying ridge. In the posterior teeth of *D. spatulatus* the alation is not broad, but it is thick, and it disappears near the outer end. *D. alatus* teeth have a thin, narrow alation along the antero-lateral border, while the antero-lateral border of *D. spatulatus* teeth is thick, has no alation, and is modified for the attachment of other teeth.

This species is referred to *Sandalodus* because it seems to have but a single tooth to each ramus of the jaw.

Formation and locality: Keokuk and Burlington limestones; Iowa and Illinois.

Sandalodus porcatus *sp. nov.*

(Plate I, Fig. 14)

Type a single incomplete tooth. Length along antero-lateral edge, 34^{mm}; breadth above alation, 14^{mm}; greatest thickness, 10^{mm}. As the outer part of the alation is missing, its full dimensions cannot be ascertained. Tooth very thick and strong at the inner end, but becoming thin along the antero-lateral border near the outer end. The postero-lateral border is thick from the outer end to the alation, but becomes quite thin along the margin of the alation. The alation resembles that of *S. emarginatus* in being convex upward and very thick and strong. It occupies considerably more than half the postero-lateral border of the tooth, and diverges from this border at an angle a little greater than 100°. Tooth strongly arched longitudinally and transversely, excepting at the outer end, where the transverse arching is much less than in *S. laevissimus* and *S.*

emarginatus. The transverse arching near the inner end is much stronger than in any other species of *Sandalodas*. The outer end was probably enrolled as much as in *S. laevissimus*, but the enrolment is partially broken away. Enamel punctation so fine that it can with difficulty be detected with the naked eye. The tooth is peculiar in having a sharp ridge along the higher part running from the outer end to the inner. From the antero-lateral border six small ridges with sharp crests pass upward and forward, joining the large ridge at the top. The posterior one of these ridges is quite strong, but they decrease in size progressively toward the anterior end of the tooth, and the anterior one is very faintly marked. No lines of growth are present.

This species differs from *S. emarginatus* in the presence of the ridges above mentioned, in its greater transverse arching near the inner end and lesser transverse arching near the outer end, in the relative width of the alation, in the fineness of the enamel punctation, and in its size.

Formation and locality: St. Louis limestone; Salem, Ind.
Paleontological Collection, Walker Museum, No. 10050.

Sandalodus latidens *sp. nov.*

(Plate I, Fig. 11)

Teeth of medium size, comparatively broad, not arched longitudinally, little arched transversely. Pointed at the anterior end. The antero-lateral margin forming a strong curve, the postero-lateral margin straight for 12^{mm} from the outer border, then diverging to form a prominent shoulder, rounded at the outer part. This shoulder extends out 8^{mm}, and from its point the postero-lateral margin passes backward in a straight line, converging slightly toward the main axis of the tooth, until it approaches the posterior border, where it curves inward and meets the antero-lateral border in the line of the main axis. Surface of enamel coarsely punctate. Lines of growth showing as delicate color markings, with no ridges present. Greatest length of tooth, 48^{mm}; greatest breadth, 27^{mm}.

The breadth, shape, and punctation of this tooth are probably of generic value, but it is here placed provisionally with *Sandalodus*, as there can be little doubt that there was only one tooth to each ramus of the jaw.

Formation and locality: Keokuk limestone; Keokuk, Iowa.
Paleontological Collection, Walker Museum, No. 10035.

Deltodus spatulatus Newberry and Worthen

(Plate I, Figs. 10, 12, and 13)

Deltodus spatulatus Newberry and Worthen, 1866 (*Paleontology of Illinois*, Vol. II, p. 100, Plate IV, Fig. 7).

Deltodus spatulatus Newberry and Worthen, 1870 (*ibid.*, Vol. IV, Plate III, Fig. 11).

Cochliodus costatus (*pars*) Newberry and Worthen, 1870 (*ibid.*, p. 364, Plate III, Fig. 12 [not Fig. 10]).

Deltodus spatulatus Newberry, 1879 (*Annual Report of the Geological Survey of Indiana*, p. 346)

Deltodopsis? convolutus St. John and Worthen, 1883 (*Paleontology of Illinois*, Vol. VII, p. 165, Plate XI, Figs. 11 and 12).

Cochliodus costatus (*pars*) St. John and Worthen (*ibid.*, p. 167).

Deltodus latior St. John and Worthen (*ibid.*, p. 145, Plate IX, Figs. 11 and 12).

Deltodus spatulatus Newberry, 1897 (*Transactions of the New York Academy of Science*, Vol. XVI, p. 292, Plate XXIX, Figs. 8–11).

Deltodus spatulatus Eastman, 1903 (*Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, Plate IV, Figs. 41 and 42; Plate V, Fig. 55).

In the collection of Walker Museum are several nearly perfect specimens of *Deltodus spatulatus* teeth from the Keokuk limestone, and a large number of more or less complete specimens from the Burlington limestone. Those from the Keokuk are generally much better preserved than the ones from the Burlington. On the Keokuk specimens a few lines of growth are usually present, but the Burlington specimens rarely have lines of growth developed. One specimen from the Keokuk is remarkable for the great development of the outer end of the tooth. It curves downward and backward, lacking about 100° of forming a complete circle. From the fact that this curved part is very slender, and consequently would rarely be preserved, it is possible that it was generally developed to a much greater degree than has formerly been supposed. The complete outer end or antero-lateral margin has not been observed in any of the teeth from the Burlington limestone.

A study of these specimens substantiates Eastman's view[1] that *Deltodopsis? convolutus*[2], and the narrow, strongly enrolled teeth called by Newberry and Worthen *Cochliodus costatus*[3] are probably the median or anterior teeth of *Deltodus spatulatus*. A great many

[1] *Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, p. 199.

[2] St. John and Worthen, *Paleontology of Illinois*, Vol. VII, p. 165, Plate XI, Figs. 11 and 12.

[3] *Ibid.*, Vol. II, p. 364, Plate III, Fig. 12? (not. Fig. 10).

teeth of this character have been found in the Burlington limestone. They are usually fragmentary, but fit the posterior teeth of *D. spatulatus*, and there are no other posterior teeth from that formation with which they can be classed.

Formation and locality: Kinderhook, Burlington, and Keokuk limestones; Illinois, Iowa, and Indiana. Numerous in the Burlington and rare in the Kinderhook.

Deltodus attenuatus *sp. nov.*

(Plate I, Fig. 6)

Tooth triangular in outline. The type specimen measures 22^{mm} along the antero-lateral border, 27^{mm} along the postero-lateral border; inner margin, 15^{mm}. Tooth slightly arched longitudinally, little arched transversely. A ridge runs from the acute angle of the posterior border to the anterior border. The tooth slopes down abruptly from this ridge to the postero-lateral border, excepting at the posterior angle, where there is an alation that turns upward. The postero-lateral border is very thin. Toward the anterior border there is no depression, the rest of the tooth being the same height as the ridge. The antero-lateral margin is very thick at the inner end, but thins out toward the outer end. The posterior inner angle is obtuse, the posterior outer angle acute. The surface of the enamel is very finely punctate throughout.

This species differs from *Deltodus angularis* (*Orthopleurodus carbonarius*) St. J. and W. in being much narrower and thinner, much less arched both longitudinally and transversely, and in the character of the ridge.

The type specimen, a posterior tooth from left mandible or right maxilla, is from the Coal Measures near Kansas City, Mo. It is now in the collection of the University of Kansas.

PLATE I

FIG. 1.—*Psephodus acutus* sp. nov. Median tooth of left mandible or right maxillary.

FIG. 2.—*Psephodus legrandensis* sp. nov. Dentition of one jaw; anterior teeth restored in outline.

FIGS. 3–5.—*Sandalodus alatus* N. and W. Fig. 4 shows the alations on both sides of the tooth. Fig. 3 has the alations restored in outline. Fig. 5 shows the characteristic punctation of the teeth.

FIG. 6.—*Deltodus attenuatus* sp. nov. Posterior tooth; anterior end and part of alation restored.

FIG. 7.—*Psephodus carbonarius* sp. nov. An almost perfect posterior tooth.

FIGS. 8 AND 9.—*Sandalodus occidentalis* Leidy. Fig. 8 shows the characteristic shape of the anterior edge of the teeth of this species. Fig. 9 shows posterior end of tooth; anterior end restored from more perfect specimens.

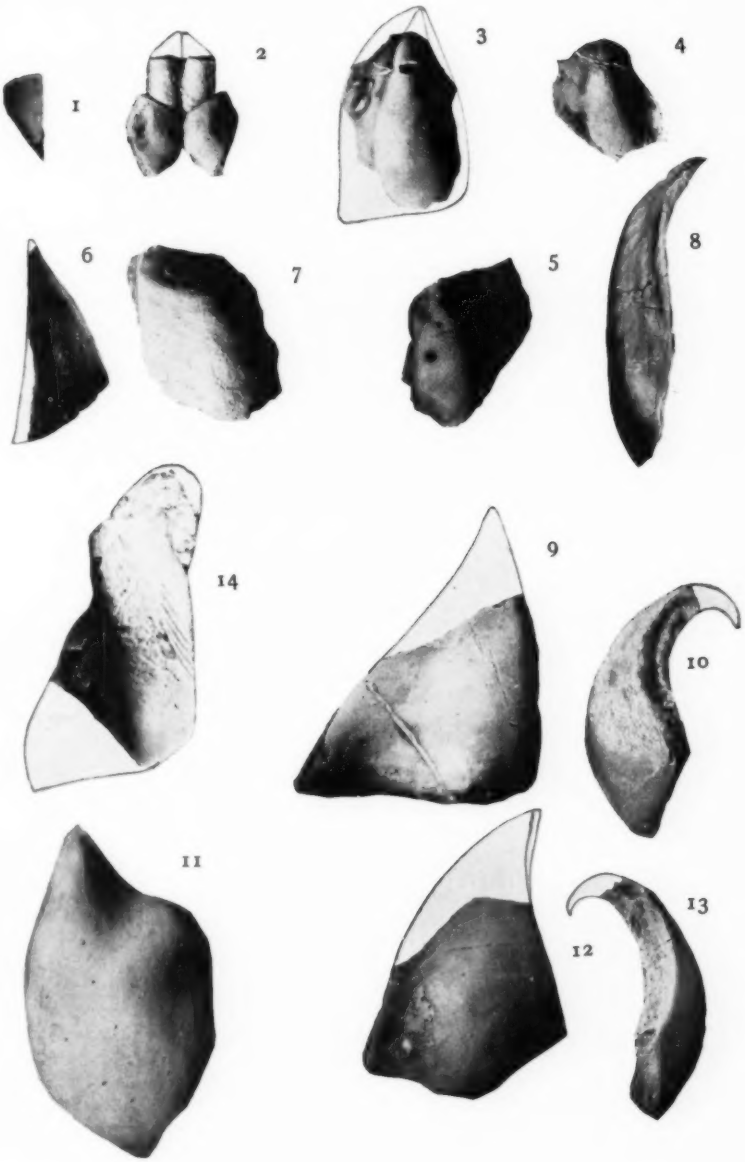
FIG. 11.—*Sandalodus latidens* sp. nov. A perfect tooth.

FIGS. 10, 12, AND 13.—*Deltodus spatulatus* N. and W. Figs. 10 and 13 show the characteristic shape of antero-lateral edge of the teeth of this species; anterior end restored. Fig. 12 shows the shape of the posterior end of the teeth of this species; anterior end restored.

FIG. 14.—*Sandalodus porcatus* sp. nov. Tooth with part of anterior end and alation restored.

PLATE II

FIGS. 1–3.—*Sandalodus emarginatus* sp. nov. Fig. 1, top view of complete tooth. Fig. 2, antero-lateral edge of same tooth; outline to show relation of postero-lateral edge. Fig. 3, postero-lateral edge of same tooth.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LAMINATED INTERGLACIAL CLAYS OF GRANTSBURG, WIS.

[WITH CHRONOLOGICAL DEDUCTIONS.]

CHARLES P. BERKEY
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GRANTSBURG, Wis., is in Burnett county. The St. Croix River forms the western boundary of the county, separating it from Minnesota. Two large streams enter the St. Croix from the east; one, known as Clam River, crosses the central portion of the county, and the other, Wood River, crosses well toward the south. Both, in their lower courses, cut entirely through the capping drift deep into a stratified clay deposit that forms the subject of this paper.

At all points the clays lie beneath a later and coarser sheet of either modified drift or till, or both. This capping varies in thickness from a few feet to possibly 50 feet, or even more. Yet the general surface of the country is extremely level over large tracts. Swamps and so-called meadows of immense size are a common feature. But the remainder of the district known to be underlain by the clay bed is typical sand barrens. That the clays extend also beneath the adjoining morainic belt forming the southeastern margin of the sand tract is indicated by characters in the deposits themselves, although their actual presence in that direction is not a matter of observation.

Extent.—One margin of the deposit is near the mouth of Wood River. The thickness there at its best exposure is only 5 feet. The broad St. Croix valley then cuts into this margin, and beyond no trace of the clays has yet been found. Exposures on Clam River lie 15–18 miles northeastward from those to be seen on the Wood. A total thickness there of over 40 feet seems to indicate that the margin in that direction is still some distance away. The same is true of the eastward extent, as noted above, while toward the west the broad St. Croix valley has destroyed the southern portion, at least on that side. There is, however, at one point on the west side of the St.

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Croix, on Snake River about 6 miles above its mouth, a deposit of laminated clays that might be interpreted as a marginal facies, but with no intervening exposures there is doubt about this connection.

Although exact boundaries, therefore, are not known, an extent of at least 20 miles north and south, and a width of 10–15 miles, are certain. Thus the area known to be underlain by these clays is about 250 square miles. The probable area is still greater, but in some directions the margins are hopelessly buried beneath heavier glacial deposits.

Thickness.—At Grantsburg 15 feet of the stratified clays are exposed in the workings of the Terra Cotta Brick Co. Mr. Ira C. Jones, the manager, at the writer's suggestion, bored entirely through the deposit, and reports a total of 35 feet at that point. There is, however, at the same place clear evidence of the removal of some of the topmost material by later ice-advance. How much should be accounted for in this way no one can tell, but the original thickness was certainly more than 35, and probably less than 40, feet.

Near the mouth of Wood River, as noted above, the same deposit is 5 feet thick.

On Clam River, with 40 feet exposed, the deposit is not entirely cut through. An undulating habit of the lowermost laminæ, however, seems to indicate proximity to the floor.

Character.—These clays are all strongly laminated. The laminæ vary in thickness from a mere film to several inches in different parts of the deposit, but are comparatively uniform in any particular zone. Their average thickness in the upper part of the deposit is about a quarter of an inch. The average thickness nearer the middle is about one-tenth of an inch. Less uniformity is observable near the top than in any other zone.

The lamination is extremely regular and approximately horizontal. Small crumplings or bunchings occur, but are rare.

The general color is red from top to bottom. On closer inspection, however, the laminæ are seen to be of two types—a deep red one, and a gray, which alternate without exception throughout the deposit.

Very perfect water-sorting is evident from a study of these individual laminæ. The gray ones are comparatively coarse-grained, containing maximum diameter of 0.06^{mm}. Diameters of 0.02 to

0.03^{mm} are very common, while of course there is much finer matter. The red laminæ are composed of extremely fine grains and flakes. There are no grains at all comparable to the sizes given above. Average diameters are less than 0.002^{mm}.

The passage from one type to the other is sometimes gradual and sometimes abrupt. As a rule, the gradual changes hold for all cases in passing upward from a gray to a red lamina. The abrupt changes are noted in passage upward from a red to a gray one. Evidently there is some sort of unity between each gray lamina and the overlying red one throughout the series.

Taking, therefore, the double lamina—*i. e.*, a gray and the succeeding red one above—as a unit, the following facts obtain: The most irregular lines in the lamination are at the very base of the gray laminæ. There are sinuosities on a small scale that simulate erosion unconformities. The coarsest grains seen anywhere in the material are in these small embayments along this line. There is an occasional streakiness of the gray laminæ with the finer red material, but not uniformly developed. The change to red, in rising from the base of the gray lamina, takes place very gradually and gives a much more even line or band than that at the base. The change to red color is no more marked than the change to finer and finer grain. There is no streakiness in the red layers.

At Clam River there is some modification of these characters. The proportion of gray material is greater. The upper 20 feet of that deposit are decidedly gray and sandy. Lower down, however, the red layers assume their accustomed character, relations, and importance, and are of even more than the usual thickness.

Composition.—Much of the clay matter is so extremely fine that identification in the grain is of doubtful accuracy. Among the coarser fragments quartz is most abundant. Feldspar, garnet, tourmaline, mica, and kaolin are also recognized. As a whole, the gray laminæ are extremely siliceous, while the red are by strong contrast argillaceous.

"Clay dogs," small limy concretions, occur in the upper part of the deposit at Grantsburg.

Chemical analysis shows a higher percentage of lime and magnesia than would be expected from the color of the material. Iron,

however, is prominent enough to overcome their effects, so that the burned wares are all red.

Where successive laminæ are so divergent in characters, it is evident that there might be considerable difference in chemical analysis from different samples. For ordinary brick-making purposes the material is mixed as thoroughly as possible with the equipment of the plant. Such a mixture would best represent the composition of the deposit as a whole. Nearly all the work yet done has been upon the upper zone of about 15 feet. Two samples out of this zone give the following results in a partial analysis. No. I is mixed material and fairly representative. No. II is from the uppermost layers.

	I	II
Silica, SiO_2	58.52%	64.76%
Alumina, Al_2O_3	14.98	15.45
Iron, Fe_2O_3	7.92	4.86
Lime, CaO	5.26	4.22
Magnesia, MgO	3.39	4.02
Water, H_2O	7.92	5.96
	97.96	99.17

This leaves a balance of 2.04 and 0.83 per cent., respectively, for the undetermined constituents.

Economic value.—With moderately thorough mixing the Grantsburg laminated clays make common stiff mud brick of excellent quality. The fineness of grain and plasticity aid in producing an unusually smooth finish. With hard burning the product is remarkably strong. The colors are all classed as red, but exhibit considerable range of shades, the hardest-burned lots being darkest in color. Likewise the more exposed margins have darker color, so that systematic setting of the kiln with this result in view produces a variegated ware that is considered attractive.

All wares require a temperature of about 2,000° F. in burning. The upper beds of Clam River are too sandy for use as clays at all. At all other points, however, with careful mixing the material is valuable for clay wares. Vitrified bricks have been made by the company now operating at Grantsburg which seem to duplicate the

most approved paving quality. Ornamental terra-cotta, however, is the most promising line of development to which this clay lends itself.

In practice the chief problem is to secure complete intermixture of the two types of laminæ. They have very different shrinkage and fusibility. When the mixing is thorough, however, the result is a clay of superior quality and capable of use in higher grades of wares.

Geological relationships.—Evidence as to the age and origin of this deposit has been in part involved in the preceding description. The laminated clays rest upon a thick accumulation of red glacial till of typical late Wisconsin character. At the mouth of Wood River this is well exposed. Occasional horizontal markings seen here throughout a thickness of about 40 feet of this till are thought to indicate standing water during its deposition. On the St. Croix, half a mile away, this same till in turn rests upon the eroded surface of white and yellow friable Cambrian sandstone.

Everywhere above the clays rests a sand or till capping, or a mixture of both. It contains coarse sand in greatest quantity, but also gravel and bowlders. At the clay pits near Grantsburg, the overlying gravelly till also contains an occasional pyritiferous and carbonaceous nodule very like those sometimes seen in lignite horizons. There are also numerous chunks, angular fragments, of laminated clay, of the size of small bowlders which, in connection with the furrowed or uneven surface of the clay deposit itself, argues a plowing up of some of this material by subsequent advance of glacial ice. The capping drift does not show water marking, and is of variable thickness, with occasional typical morainic aspect. Wherever the surface is level for any considerable area the sloughs and meadows are found. These are a surprising phenomenon in a country that appears to be all sand, but no doubt the effective bottom is formed by the underlying laminated clay beds.

It is clear that the clay deposit was accumulated some time in the late Wisconsin stage of the Glacial period. Heavy deposits of Wisconsin till preceded the clays, and there was a readvance of the ice covering the whole area again after the laminated clays were laid down. The thin cap left by this last advance, and the little disturbance of previous deposits, argue a place at the immediate close of the stage for this locality.

The larger development of sands immediately upon and after the deposition of fine clays of so great extent seems to indicate a long-continued assorting of materials, carrying the fine matter forward and leaving the coarser behind, until a final movement of the chief agency brought them both together a second time—but this time in separate beds. The prevailing sandiness of the upper portion of the laminated deposit at Clam River leads one to regard that direction—*i. e.*, the north or northeast—as nearest to the general supply. This is the region also that constitutes the typical sand barrens of northern Wisconsin. The long, assorting process must have been as prominent a genetic factor with them as the type of bed-rock from which they were obtained.

The laminated clays.—The laminated clays are no doubt a lake deposit. The uniform succession of laminæ, the relationship between the red and gray, and the constancy of their characters lead one to look for some uniformly periodic cause of formation.

The presence of comparatively large grains throughout the gray laminæ shows a continuance of supply of new material during its accumulation at least, while the presence of some streakiness of finer red matter occasionally in them indicates fluctuations or lulls within this period of supply.

The absence of all large fragments in the red laminæ, their uniformity of succession, and their gradual increase in fineness of grain seem to argue a period of complete cessation of supply from without and complete protection from disturbances.

This periodic supply, then, must mark either successive storms or successive thawings of neighboring glacial ice. If the latter, then the period is seasonal, and each unit of lamination, a gray and a succeeding red layer together, represents a year of time. On this supposition, the summer thawings of the glaciers furnished silt to the lake then covering the Grantsburg area, and left behind great quantities of coarser materials to be later spread as the poorest of northern soils. Winters checked the supply, coated the lake with ice, and in this quiet season the finest sediment settled down in the uniform red laminæ of the clay deposit.

The deposits themselves have further evidence on this point. It is scarcely conceivable that a supply controlled by spasmodic periods,

such as storms, could produce uniformity either in thickness or in distribution. Variations would be expected to be notable and frequent, and at random with occasional breaks of a much more pronounced character. On the contrary, at any given horizon the thicknesses are comparatively uniform and there are no breaks of a higher order than those of the single unit. If, furthermore, the succeeding laminæ represent seasonal supply from a more or less proximate ice margin, succeeding seasons might be expected to give fairly equivalent results, greatest uniformity being developed when the ice margin is distant, and greatest variation when the ice is nearest. Other things being equal, when the supply is near by, a greater quantity of matter would reach the lake in a given season, and in connection with the general tendency or character of the season there ought to be more irregularity and greater thickness of deposit. In terms of the clays themselves, the laminæ of the middle zone should be most uniform and of least average thickness, while those of the top and bottom zones should be most variable. This is easily seen to be true in the deposit. The greatest irregularities are near the top. With a retreat of the ice margin to near its maximum withdrawal the middle zone of laminæ must have been laid down. A seasonal interpretation accords well with the facts. Even the streakiness seen in the thicker gray layers makes room for storms or other fluctuations within the season itself, and supports the other interpretation for the more uniform breaks.

If the seasonal interpretation may be regarded as established, it remains only to compute the number of units of deposition in order to estimate the number of years the deposit was in accumulating. This done, we need but to connect this episode in the general ice-retreat with its proper limitations in order to get the force of its bearing upon postglacial history.

Time estimates.—For computation a gray and red lamina together make a unit and represent one year. At Grantsburg the deposit is now 35 feet thick, and was originally greater. There are an average of four units to the inch, or forty-eight to the foot, in such portions of the bed as can be critically examined at that point. There are then approximately 1,680 units in the total thickness. It seems fair to conclude from the above computation that the interglacial lake,

producing the laminated clays at Grantsburg, existed 1,700 years, and that the accompanying minor retreat and readvance of the ice-margin consumed the same length of time.

The whole problem of time relation to geologic process is a difficult one. There is no very satisfactory formula for the solution of either a process or an interval in so exact terms as years. The most successful attempts at such solution are for the interval between the final withdrawal of the ice from particular localities and the present time. For the vicinity of Buffalo by means of Niagara Falls, and for the vicinity of Minneapolis by means of St. Anthony Falls, careful estimates have been made and are widely known. In both cases, however, there are variable factors capable of modifying any particular result seriously, and even multiplying the lower estimates many times. The lowest estimates are in general those either published earliest or those which pay the least regard to possible variation of the factors. But there is so far no more precise estimate as to this interval, or any part of it, from any other source.

It is believed, however, that the Grantsburg clay beds furnish just such data, and that, so far as they go, they are more precise than the two familiar examples cited above.

The interval covered by this estimate of 1,700 years measures only one of the minor oscillations of the Lake Superior ice-lobe. In its whole retreat from St. Anthony Falls to the highlands of its source there were doubtless several similar fluctuations. Evidence of this in part is the great development of terminal moraines piled across the region, and the occurrence of similar laminated clay beds at other localities. It would seem as though the time actually required for the retreat of the ice from St. Anthony Falls to Lake Superior alone must have been at least as great as the smallest estimates formerly made for the whole postglacial interval.

Summary.—A laminated clay bed 35 feet thick is exposed on Wood and Clam Rivers in Burnett county, Wisconsin.

The area estimated to be underlain by this deposit is more than 300 square miles in extent.

Excellent bricks are being made, and the material is capable of more uses.

The deposit is of lake origin fed by melting glacial ice.

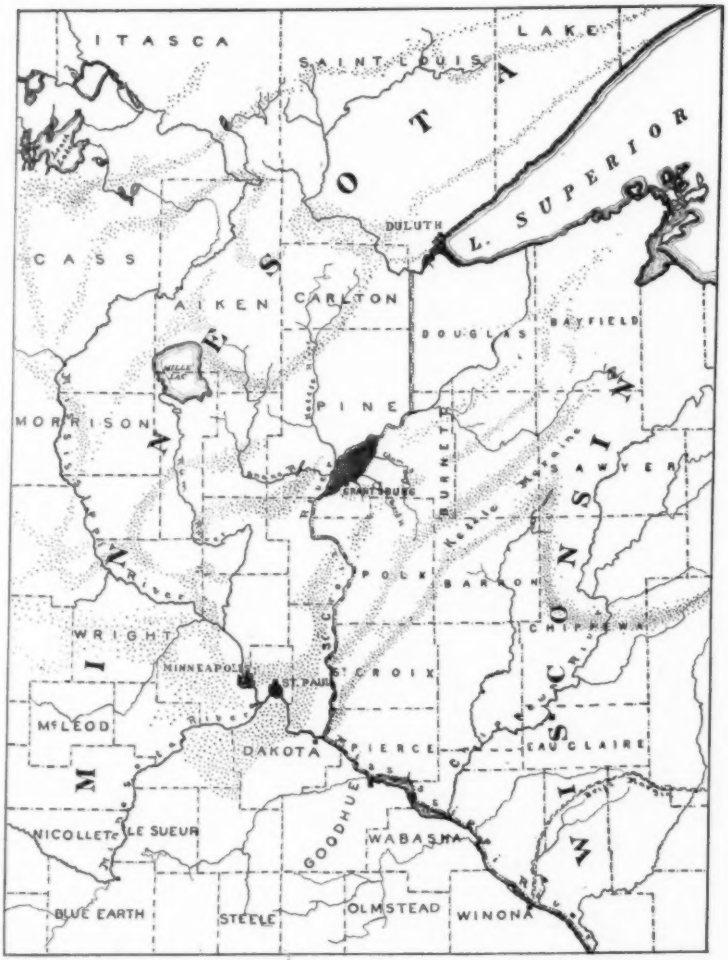

FIG. 1.—Region about the head of Lake Superior, showing location of the Grantsburg clay deposit, and its general relation to the major terminal moraines of the vicinity. (Compiled from the maps of the Minnesota and Wisconsin State Surveys.)

Its age is late Wisconsin stage of the glacial period, and is in a minor way interglacial.

The character of lamination is considered to indicate a seasonal accumulation. Each unit of lamination, therefore, measures a year.

The total thickness of the deposit divided by the average thickness of the unit of lamination gives a number equivalent to the length of time occupied in its accumulation. This is approximately 1,700 years.

If correct at all, the above furnishes a more precise measure for a part of the postglacial interval than is obtained from any other source. The part of this interval involved is but one of the minor fluctuations of the retreating ice in the vicinity of Grantsburg, Wisconsin.

Evidence from this source is opposed to the lowest estimates of postglacial time as computed from Niagara and St. Anthony Falls.

THE NEW MADRID EARTHQUAKE[1]

EDWARD M. SHEPARD
Springfield, Mo.

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GENERAL STATEMENT

Several papers, recently published, have shown an awakening interest in the region called the "sunk lands" in southeastern Missouri and northeastern Arkansas, which, as an older writer has stated, presents one of the few examples on record of the incessant quaking of the ground for several successive months far from any volcano; but so far as the present writer has been able to find, no theory or suggestion as to the probable cause of the violent phenomena exhibited in the region of New Madrid, either at the time of, or subsequent to, the period of greatest violence, has been proposed.

During the summer of 1904 the present writer had an opportunity, in connection with an investigation of the artesian waters of Missouri for the United States Geological Survey, to make several trips into the region, in one of which he was accompanied by Mr.

[1] Published by permission of the director of the U. S. Geological Survey.

M. L. Fuller, under whose general direction the study of the artesian waters was conducted. The trips presented numerous opportunities for the observation of earthquake phenomena, often still clearly visible, and for studying their possible connection with artesian-water conditions. It is with a view to calling attention to this relation that the present paper is prepared.

PHENOMENA OF THE EARTHQUAKE

All writers on this subject refer to the earthquake as having been widespread in the then thinly settled region of the Mississippi basin, and express surprise at the exhibition of such violent phenomena occurring so far from the seacoast or volcanoes, and so distant from regions where the earth's crust is known to be in an unstable condition.

Description of the earthquake.—The circumstance of the earthquake has been graphically described by various observers, and an excellent collection of statements in regard to it has been published by Dr. G. C. Broadhead.[1] In order that the phenomena may be more vividly recalled by all, we quote from these extracts:

> A letter from L. Bringier, which had been published in the *American Journal of Science, Vol. III, 1821*, states that the shock was felt for 200 miles around. There seemed to be a blowing out of the earth, bringing up coal, wood, sand, etc., accompanied with a roaring and whistling produced by the impetuosity of the air escaping from its confinement, which seemed to increase the horrid disorder of trees being blown up, cracked, and split, and falling by thousands at a time. The surface settled, and a black liquid rose to the belly of the horses, which stood motionless, struck with panic. Afterward the whole surface remained covered with holes, which resembled so many craters of volcanoes, surrounded with a ring of carbonized wood, and sand which rose for about 7 feet. A few months after, these were sounded and found to exceed 20 feet in depth. Now it is covered with ponds and sand hills or monticules, which are found where the earth was formerly lowest. There seemed to be a tendency to carbonization in all vegetables soaking in the ponds, produced by these eruptions. A lake was produced 27 miles west of the Mississippi, with trees standing in the water 30 feet deep.

Another interesting account[2] of the earthquake is given by Godfrey LeSieur, an old inhabitant of New Madrid County. He says that—

[1] *American Geologist*, August, 1902.

[2] Switzler, *History of Missouri*, and Campbell, *Gazetteer of Missouri*.

The first shock came at 2 A. M., December 16, 1811, and was so severe that big houses and chimneys were shaken down, and at half-hour intervals light shocks were felt until 7 A. M., when a rumbling like distant thunder was heard, and in about an instant the earth began to totter and shake so that persons could neither stand nor walk. The earth was observed to roll in waves a few feet high, with visible depressions between. By and by these swells burst, throwing up large volumes of water, sand, and coal. Some was partly coated with what seemed to be sulphur. When the swells burst, fissures were left running in a northern and southern direction, and parallel for miles Some were 5 miles long, 4½ feet deep, and 10 feet wide. The rumbling appeared to come from the west and travel east. Similar shocks were heard at intervals until January 7, 1812, when another shock came as severe as the first. Then all except two families left, leaving behind them all their property, which proved to be a total loss, as adventurers came and carried off their goods in flat boats to Natchez and New Orleans, as well as all their stock which they could not slaughter. On February 17 there occurred another severe shock, having the same effect as the others, and forming fissures and lakes. As the fissures varied in size, the water, coal, and sand were thrown out to different heights of from 5 to 10 feet. Besides long and narrow fissures, there were others of an oval or circular form, making long and deep basins some 100 yards wide, and deep enough to retain water in dry seasons. The damaged and uptorn country embraced an area of 150 miles in circumference, including the old town of Little Prairie [now called Caruthersville], as the center, a large extent on each side of Whitewater, called Little River, also both sides of the St. Francis in Missouri and Arkansas. Reelfoot Lake, in Tennessee, sank 10 feet.

Features of the earthquake area.—This disturbed area extends from a point south of Cape Girardeau for 200 miles to a locality north of Wynne, Ark., and reaches from the eastern bluffs of the Mississippi to the foothills of the Ozarks a distance of from 30 to 40 miles. It includes most of Lake County, Tenn., a number of counties in southeastern Missouri, and several in northeastern Arkansas. Dr. W J McGee, in his paper on "A Fossil Earthquake," states that—

With a single exception, the traveler by steam packet on the lower Mississippi finds the river flanked by alluvial banks so low that during great freshets they are overflowed all the way from Cairo to the Gulf, save where protected by natural or artificial levees.

The exceptional area he describes as a low dome, which bulges upward 20 or 25 feet above the general level of the alluvial plain. This dome

[1] *Bulletin of the Geological Society of America*, Vol. IV, pp. 411–13.

is made up of a series of more or less parallel ridges, swamps, and shallow lakes. Where the Mississippi River cuts through it the banks exhibit large deposits of sand and alluvium underlaid by a thick bed of tenaceous blue clay—the Port Hudson clay. Not only is an unconformity exhibited between the alluvium and clay deposit, but from New Madrid nearly to Osceola the bed of clay has an irregular, wave-like outline, and in places is abruptly faulted. Stumps

FIG. 1.—View on swamp bordering Varney River, near Kennett, Mo. (Photographed by M. L. Fuller.)

are frequently seen imbedded in it, occasionally in a series, one above the other, extending from below low-water mark to a height 25 feet above that mark.

McGee calls attention, in his paper, to the dry bayous that squarely and obliquely enter Reelfoot Lake—a sunken lake in Tennessee, saying that "when this occurs there is no sign of delta-building, and both channels and natural levees may be traced long distances in the lake." He also says: "This absence of deltas indicates that the uplift or deformation occurred suddenly."

A careful study of the whole district of the dome indicates that it has been lifted above the general alluvial plain of the Mississippi. We have spoken of the narrow, more or less parallel, ridges, alternating with narrow, irregular lakes and swamps. Frequently the line between the swamp and ridge is abrupt and terrace-like. Near Gayoso a striking example of this configuration occurs. Here the general level of the ridge breaks abruptly in a straight line, and drops some 4 or 5 feet to the general level of the swamp, forming what even the countryman recognizes as a fault scarp, and describes as "the place where the land sunk."

FIG. 2.—East side of Varney River, below Kennett, Mo. (Photographed by M. L. Fuller.)

The streams which flow through this district are very tortuous and generally, though not always, follow the line of the swamps. Instead of flowing into the Mississippi, they usually flow at a slightly divergent angle, and empty into the St. Francis. There is a strong and decided slope southwestward through this area from the Mississippi to the White River, the valley of the latter being there decidedly lower than the valley of the Mississippi. A large amount of water flows southwestward through this area, and it is noticeable that, while the vegetation has the characteristic luxuriance of the swamps, the water is relatively clear, pure, and cool, and alive with bass and other game fish supposed to inhabit only those waters which are moderately pure and cool. It is further remarkable that the bot-

toms of these streams are usually hard and sandy, with little or no muck, as is usually so common in swamps.

The elongated lakes are, as a rule, shallow, although there are some exceptions. Reelfoot Lake, in Tennessee, for example, is from 20 to 25 miles long, and from 4 to 5 miles wide, with a depth of from 20 to 30 feet. Its area is perhaps doubled in time of high water. It is deeper at the northeast than at the southwest end. The water of this lake, as well as of the others in the area under consideration, is clear and pure, and not yellow and turbid, like the waters of the Mississippi. On this lake one may float over submerged treetops, and on Golden Lake, near Wilson, Ark., as well as on others in the district, the same submergence of trees may be observed. Tyronza and Crooked Lakes are both sunken lakes fed from below by clear and relatively cool water, Crooked Lake being irregular in depth, with many deep holes in the bottom. Mr. C. B. Bailey, of Wynne, Ark., to whom the writer is indebted for personal guidance through a portion of this district and for many valuable notes, states that Little Black Fish Lake, near Parkin, Ark., 1 mile long and 200 feet wide, has a depth of from 50 to 60 feet. The water is clear and cool, and hunters sink their venison into it for preservation. Other lakes in the vicinity are shallow, being only from 5 to 15 feet deep. It is noticeable that these sunken lakes vary decidedly in the amount of subsidence. Maximum amounts are found in Reelfoot and Crooked Lakes, where the forests are entirely submerged. In others we find the timber but half-buried, and in still other instances the surface is lowered but a few feet. Several miles west of Kennett, in the swamps on the Varney River, the line of sinking is marked in a most interesting way. To the east of a north-and-south line at one point in the swamp, the timber grows tall and erect, in its normal position, while on the west it appears to be submerged to a depth of from 10 to 15 feet. There are areas where the land has been sunken, the timber killed, and the depression partially refilled with flood deposits, upon which has sprung up a new vegetation of a character entirely different from the old. In the Big Bay district, north of Wynne, Ark., the dry bayous are covered with stunted trees of willow and honey locust, while on the slightly higher land on either side are the giant cypresses and gums.

Fault scarps.—The fault scarps are a striking feature of the country, especially in the Big Bay district. Two nearly parallel lines of cracks having an east-and-west trend are found near the mouth of Fortune Creek, where it empties into the St. Francis. Others in the same vicinity have a northeast-and-southwest trend, with a present depth of about 4 feet. One of these cracks, illustrated in the photograph (Fig. 3), has growing from it a tree which is probably seventy-five years old.

FIG. 3.—Fault scarp, ten miles north of Parkin, Ark., in the Big Bay district.

Ejection of sand.—Another feature of this region, and one which will be referred to later, is the large amount of white sand that constitutes the surface of the New Madrid district. Passing down the Mississippi River from St. Louis, the amount of sand on the banks is not relatively large. On entering the sunken district, we find a small amount of coarse sand, which is evidently derived from the breaking down of the Ordovician and Cambrian sandstones of the country above, and proceeding southward we find a steady increase in the amount of fine white sand which, everywhere forms the surface of the flats, reaching a maximum thickness in what is called the "sand slew" country, at the southern end of the area under dis-

cussion, 20 miles north of Wynne. The land here is frequently too poor to support much vegetation. There is little or no loam, and arid patches of sand are common. Along the edges of the cracks and fault scarps large deposits of sand are frequently found. Another peculiar feature of the country which should be mentioned is the presence of "sand blows"—low mounds of fine white sand mixed with small pieces of lignite. These mounds are 3 or 4 feet high, with a diameter of from 20 to 100 feet, and are frequently slightly

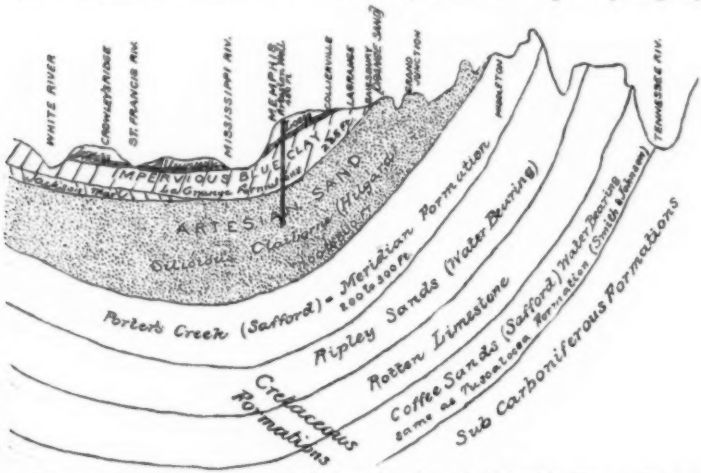

FIG. 4.—An east-and-west geological section through Memphis, Tenn. Vertical scale exaggerated about 250 times. The Orange Sand (LaFayette formation) lies between the Artesian Sand and the Impervious Blue Clay of the diagram. (From J. M. Safford's report to the Artesian Water Co., of Memphis, Tenn.)

hollowed in the center. They are scattered over the whole district, and the sand is so pure that it will not support vegetation, and consequently barren patches mark their site.[1]

ASSOCIATED ARTESIAN CONDITIONS

The Mississippi Valley forms a strong artesian basin between the Tennessee Mountains and the Ozarks. Referring to the geological section and map adapted from the report on *The City Water Supply of Memphis*, by Safford, it will be noticed that loess covers

[1] The inhabitants claim that wells driven in these "sand blows" give a better quality of water.

Crowley's ridge on the west, and the bluffs on the east side of the valley, while sand and alluvium cover the area under discussion. Beneath the loess is from 6 to 40 feet of Lafayette gravel, followed by a layer of impervious blue clay—the La Grange formation, which varies greatly in thickness, and averages from 100 to 225 feet. Under this impervious blue clay is from 10 to 40 feet of Orange sand, and below this is found the great water-bearing sand, the Silicious Claiborne, or the La Grange sand of the La Grange formation of Hilgard, which varies in thickness from 600 to 800 feet. This deposit of sand, which is finer in texture above and below than in the middle, and which is intercalated with thin beds of clay and a considerable amount of lignite, is a reservoir in which the waters from the Tennessee Mountains and the Ozarks meet under great pressure. Beneath this sand is found from 200 to 300 feet of Porter's Creek (Safford), or Meridian, formation, and under the last is about 250 feet of Ripley sands, another water-bearing formation, the source of the artesian waters of Jackson, Miss., while still lower is the Rotten limestone overlying the Coffee sands, which, in turn, rest unconformably upon the Sub-Carboniferous.

Numerous drill-wells through and around the sunken district develop the fact that the wells of the region do not flow, but that the water rises to or very near the surface, while those on the border of this district are mainly artesian, or flowing, wells. Starting at Memphis, where there are 140 flowing wells, and going northward along the border of the district, a flowing well 628 feet deep is encountered at Dyersburg, Tenn.; one 840 feet, at Hickman, Ky.; one 930 feet, at Wystaff, Ky.; several over 800 feet, at Cairo, Ill.; one 626 feet, at Mound City, Ill.; one 710 feet, at the mouth of Cash Creek, Ill.; one 62 feet, at Pocahontas, Mo., north of Cape Girardeau; one 900 feet, at Campbell, Mo.; and one 480 feet, at Parkin, Ark., west of Memphis.

In the sunken area which is encircled by these flowing wells there are non-flowing wells at Terrell, Ark., 860 feet; north of Memphis, 800 feet deep; at Deckerville, Ark., 700 feet; at Caruthersville, Mo., 428 feet; at New Madrid, Mo., 200 feet; and at Sikeston, Kennett, and Marked Tree, Mo. The waters in the flowing well at Cairo are probably derived from the St. Peter's sandstone.

Here we find the anomalous condition of a great artesian basin where the wells flow in a circle surrounding the center, but rise to the surface only on the low ridges within this circle. The constant and vast seepage along fault lines and low places, accomplished by springs to be later described, keeps down the stronger artesian pressure which is seen on the outer borders of the area.[1]

Sand brought up in wells.—Messrs. W. G. Lanhan and W. C. Davis, engineers for the Memphis Water Co., state that of 141 wells that have been sunk in Memphis nearly all flow when they are not pumped, and that the altitude to which the water rises, when not pumped, is 218 feet above Biloxi, Miss. These gentlemen both say that there is a continuous flow of fine sand carried up to the surface by the water of all these wells from depths varying from 450 to 600 feet. A brass strainer, with openings one hundred-and-fiftieth of an inch in width, is placed in the bottom of each well, and this is so rapidly worn by the sand that it has to be replaced in from three to five years. Every precaution is taken to keep this sand from the valves and piston rods of the pumps. The wells are tapped at depths of from 40 to 60 feet, and the water is conveyed by large brick tunnels 5 feet high to a central reservoir well at the pump station. The sand collects so rapidly in these tunnels that they must occasionally be cleaned out. One tunnel was found nearly filled with sand deposited from the water.

Mr. Henry Moss, of New Madrid, Mo., was connected with the Missouri River Commission some twenty-five years ago, when a series of wells was sunk along the river and on the islands from Lister's Island, 20 miles north of New Madrid, to Fort Pillow, near Osceola, Ark.—a distance of about 90 miles. These wells were bored from 125 to 200 feet deep, and he states that the sand and water would shoot up into the pipes to within 30 feet of the surface, the sand frequently clogging the bottom of the pipe.

[1] The writer is greatly indebted to Mr. W. B. Johnson, of Memphis, Tenn., for various sections and data relating to the wells of this district. He calls attention to the similarity in composition of the waters on the east side of the basin; also to the purity of these waters, which undoubtedly have their source in the Tennessee Mountains. These are in striking contrast to the waters on the west side, which are generally saline, and which have their source in the Ozarks. He further states that the La Grange sands at Memphis are 800 feet thick, while at Pine Bluff, Ark., they are only 40 feet.

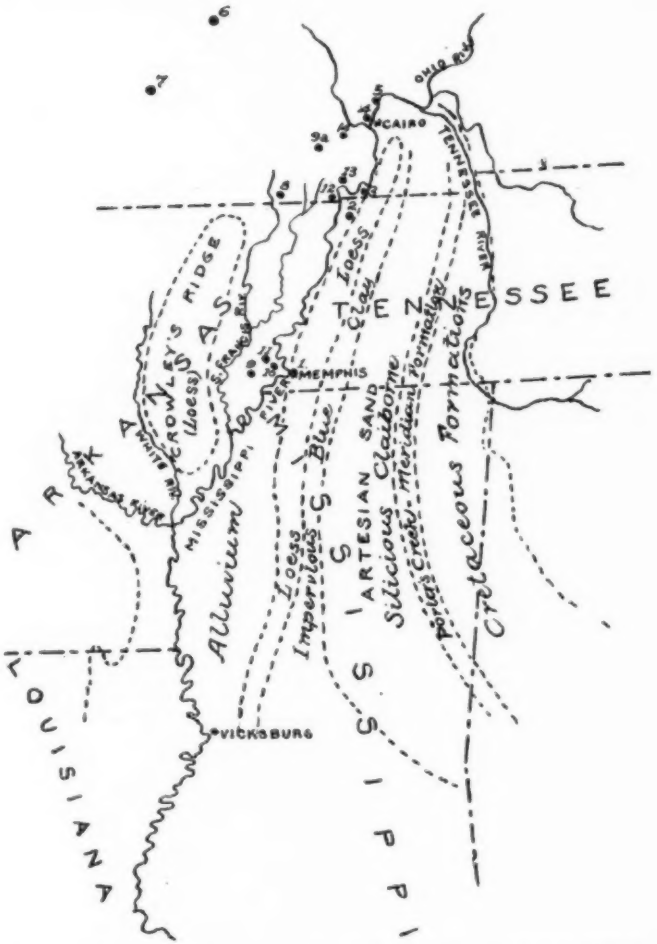

FIG. 5.—Plan showing the outcrop of geological strata east and west of Memphis. Scale: 1 inch = 90 miles. (Adapted from J. M. Safford's report to the Artesian Water Co. of Memphis, Tenn.) Flowing wells occur as follows: (1) Memphis, Tenn.; (2) Dyersburg, Tenn.; (3) Hickman, Ky.; (4) Cairo, Ill.; (5) Mound City, Ill.; (6) Pocahontas, Mo.; (7) Grandin, Mo.; (8) Campbell, Mo.; (9) Parkin, Ark.; and non-flowing wells at (10) Terrell, Ark.; (11) Deckerville, Ark.; (12) Caruthersville, Mo.; (13) New Madrid, Mo.; (14) Sikeston, Mo.

Sand brought up by springs.—We have noted the character of the water in the sunken lakes and streams—its clearness, purity, and temperature—and that the streams, where sounded, seem to have a hard, sandy bottom, and a general absence of muck. We have further referred to the great volume of pure water that is everywhere flowing out of this sunken district, and also to the abundance of game fish which only thrive in pure spring water. That typhoid fever is almost wholly unknown in this district is another fact bearing on the purity of its water supply. The people drive a pipe with a strainer 10 or 15 feet into the sand, and obtain an abundance of reasonably pure water, which they pump to the surface.

A careful study of these streams, especially along the St. Francis, the Little Tyronza and the Big Bay, reveals the fact of the constant escape of water from below through small openings surrounded by little cones of sand. This is noticeable for miles along the St. Francis and in the Big Bay district, especially on the bluff side of the streams.

Deep-seated water, then, is constantly coming to the surface, bringing with it fine sand from below. It is probable that old fault lines through the clay permit this constant discharge, which must slowly and steadily produce an undermining of the clay layer by the removal of the sand below. A glass of water taken from the springs, though seeming quite clear, will deposit, in a few minutes, a fine film of sand at the bottom. Mixed with the little sand-cones that surround the spring outlets are minute particles of lignite, which further indicate the deep source of these waters.

The soil is generally very thin, especially in the southern part of this district, where the sand deposit is thicker, and the surface sand, for several inches, is destitute of the fine particles of lignite, the absence of which is partly due to the action of surface waters in carrying the lighter particles away. Earthworm castings, however, wherever found, show the presence of the lignite. This sand that is spread over the greater portion of the sunken district, in size of grain, structure, general appearance, and association with lignite, closely resembles the drill samples obtained from the Silicious Claiborne, or La Grange formation, and justifies the conclusion that it has been thrown up from below.

A careful microscopical study of these sands confirms this impression. Under the microscope we find them to be made up of varying mixtures of small, beautiful, rounded, incoherent, water-worn grains of quartz, ranging from limpid or pellucid to perfectly transparent, glass-like particles. Occasionally, rounded grains of red, yellow, or black jasper occur, and in all samples fragments of lignite are seen. The samples studied were obtained from the artesian wells at Memphis, the small springs scattered over the district, the fault scarps, and many localities throughout the whole sunken area. The apparent identity of the surface and artesian sands is very plain.

Source of sand covering surface of "sunk area."—Testimony from various witnesses establishes the source of much of the sand distributed over this area. Eliza Bryan, of New Madrid, in a letter to Lorenzo Dow, dated March 22, 1816, speaks of the awful darkness of the atmosphere, which was saturated with sulphurous vapor, and of the fact that during all the hard shocks the earth seemed horribly torn to pieces, while the surface of hundreds of acres was from time to time covered over, for various depths, with the sand that issued from the numerous fissures. She says: "Some of these fissures closed up immediately after they had vomited forth sand and water. What seemed to be coal was thrown up with the sand in some places." A. N. Dillard, of New Madrid, stated to Professor J. W. Foster that the shocks continued from twenty to thirty months, and that in every instance the motion was from the west or southwest. He said: "Fissures would be formed from 600 to 700 feet long, and 20 to 30 feet wide, *through which water and sand spouted 40 feet high.*"[1]

Mr. Timothy Flint published in his *Book of Recollections* that "a tract near Little Prairie, now called Caruthersville, became covered with water 3 or 4 feet deep, and when the water disappeared there remained a stratum of sand." Further, that "there were two classes of shocks—those in which the motion was horizontal, and those in which it was perpendicular."

In the description by Godfrey LeSieur, given on a previous page, attention is called to the large volume of water, sand, and coal that was thrown up. Dr. Hildreth, in Wetmore's *Gazetteer of Missouri*, states that—

[1] Italics are the writer's.

The earth on the shores [of the Mississippi River] opened in wide fissures, closing again, and water and mud, in huge jets, were thrown higher than the treetops. The atmosphere was filled with a thick vapor or gas. . . . . The sulphurous gases discharged during the shocks tainted the air, and the river water, for 150 miles below, could not be used for a number of days.

Hon. Lewis F. Linn, of the United States Senate, states in a letter concerning this earthquake that "the earth rocked to and fro, vast chasms opened from which issued columns of water, sand, and coal, accompanied by hissing sounds."[1]

To sum up the testimony of most observers, we have emphasized the fact that the disturbance came from the west; that the ground rolled in great waves; that numerous fissures were formed; that great volumes of "sulphurous vapors," water, sand, and lignite were thrown up at various heights; that large areas were covered with water, the subsidence of which was marked by a thick coating of sand; that these shocks continued for nearly three years; and that the waters of the Mississippi receded for several minutes.

Further, we find today that large volumes of water are constantly coming to the surface as springs in this district; that these springs are numerous along the lines of fissure; that deep artesian wells around this region bring up this same variety of sand with lignite, some, as at Memphis, when first sunk, ejecting large chunks of the lignite; that the sand and lignite brought up in the deep wells are similar to the same substances brought up by the innumerable springs that feed the lakes and streams of this district, and that they are apparently the same as that which surrounds the blow-holes and fault scarps, and which covers, as with a vast sheet, the considerable areas in the sunken district.

Relation of the earthquake to artesian conditions.—If one studies the phenomena of the earthquake as seen by the observers quoted in this article, he cannot help being impressed with the fact that the conditions as described are identical with what would be expected to occur from the undermining of the clay horizon by the slow and continuous removal of large bodies of sand. In this process of undermining a time would come when a slight disturbance would destroy

[1] The above quotations are taken from Dr. Broadhead's collection of letters and documents relating to the earthquake, published in the *American Geologist* for August, 1902.

the equilibrium, and when the great pressure of the artesian water below would burst forth, causing the elastic clay roof to undulate, with the resulting earth-waves and ejections of water, sand, and lignite so vividly described by numbers of eyewitnesses of the catastrophe. The first disturbance, relieving, to a degree, the artesian pressure, would be followed by a temporary equilibrium, which would be succeeded by other periods of disturbance, as described.

RECENT EARTHQUAKES

This region has for many years been subject to slight earthquake shocks. A year rarely passes without their occurrence, the last one having as recent a date as September, 1904. In August, 1903, houses were shaken and dishes rattled, the phenomena lasting about ten minutes, and being accompanied by a roaring sound underneath. This earthquake was rather severe near Charleston, Mo., where a pond 3½ miles from the town was greatly enlarged by the sinking of adjacent land. The disturbance was attended by the throwing up of a considerable quantity of fine white sand. Mr. W. M. Timbs, a railroad conductor, stated that on October 5, 1895, quite a severe earthquake occurred in this region. At this time, south of Belmont, the water flowed from the driven pumps in this vicinity, and brought up sand and particles of coal, the pumps continuing to flow for a month. Numerous small cracks were formed on the prairie, from which sand and particles of coal were ejected. The writer's attention was called to the fact that one or more of these earthquake shocks occur each fall, being more frequent at that season of the year than at any other time. This might be accounted for by the low water in swamps, streams, and ponds following the dry season characteristic of the country—a condition which would give decreased pressure at the surface and offer least resistance to the artesian pressure below. Observers state that these shocks are always accompanied by a roaring noise and a waving of the ground.[1]

Some of the intense local disturbances in the Charleston, S. C.,

[1] Mr. W. S. Randall, of Poplar Bluff, Mo., informs the writer that in a well sunk there to a depth of 700 feet, a number of years ago, the water rose to within 15 feet of the surface. A twelve-horse-power engine could lower it only about one inch; but after a severe earthquake shock, about three years ago, the well was nearly ruined, and since then furnishes barely enough water to run a factory.

earthquake district, which is also an artesian district, may have been due to the long and slow undermining of superincumbent beds by the removal of sand by artesian pressure. Visitors to this region have informed the writer that large quantities of sand were thrown up at various places during the shocks, and that springs bringing up sand still issue from the fissures thus made, similar to those described in the Big Bay district.

COMPARISON WITH CONDITIONS NEAR SHREVEPORT, LA.

Several visits to the region around Shreveport, made a number of years ago, revealed a condition similar to those of the New Madrid area, and suggested the probability of the agency of earthquakes in producing the lakes, swamps, and deposits of sand so characteristic of this portion of the state of Louisiana. Shreveport is likewise an artesian region, and in its geological structure is similar to that of New Madrid. Sunken lakes covering forests occur there, as described by Lyell,[1] who calls attention to these sunken lakes as illustrating the changes now in progress in the earth's crust. In the Red River region of Louisiana he mentions Lake Bistineau, which is 30 miles in length and from 15 to 20 feet deep, and on which one may float over a submerged forest. He also refers to Black, Caddo, Spanish, and Natchitoches Lakes, and does not agree with Darby's view that the gradual elevation of the bed of the Red River by the accumulation of alluvial material has raised its channel and caused its waters, in flood time, to flow up the mouths of some of its tributaries and to convert parts of their courses into lakes. Lyell says that—

> Most probably the causes assigned for the recent origin of these lakes are not the only ones. Subterranean movements . . . . have altered the levels of various parts of the basin of the Mississippi.

Mr. A. C. Veatch says in a paper on the Shreveport area:[2]

> The valley region above Shreveport is possibly unique in the respect that changes, which usually occupy great periods of time, and whose full story can only be learned by deduction, have taken place here within a few years. Lakes have been formed and destroyed; streams formed and abandoned; waterfalls produced to destroy themselves; new streams formed out of parts of the beds of old ones; and temporary reversals of the drainage system have been effected.

[1] Lyell, *Principles of Geology*, Vol. I, p. 457.

[2] Geological Survey of Louisiana, *Report for 1899*, p. 152.

On p. 159 of this same report we read:

> Connected with Sodo Lake by Big Willow Pass is Ferry or Fairy Lake. It differs from Sodo by having hills on both sides; being exactly the same type as Cross Lake, a lake occupying an old stream valley. Ferry Lake is quite shallow, with a narrow line of deeper water winding irregularly through it. This lake is rendered particularly interesting by the large number of cypress and oak stumps standing upright in it, even in the deepest water.

The same author says further, on p. 185:

> On the recent origin of the lakes in the upper part of the valley there can be little question. A number of planters of Red River bottoms have repeated to me the old Caddo Indian tradition that about 150 years ago the land now occupied by Sodo Lake was an oak ridge, that all the water flowed in a narrow cypress-fringed bayou in the center, and that the filling of the valley was sudden, as if by an earthquake.

PRIMARY CAUSE OF THE NEW MADRID EARTHQUAKE

As to the primary cause of the New Madrid earthquake, it is difficult to make any statement. It may have been due to the readjustment of fault lines in the Ozarks, or to a similar cause in the Appalachians. It would seem more likely to have been the former, as the fault scarps in the Ozarks frequently have an appearance that does not betoken great age and, further, slight earthquake shocks, which observers described as coming from the west, have been noticed.

As to the cause of the great local disturbance in the New Madrid region, there can be no doubt that it was due to the great artesian pressure from below, which slowly undermined, for centuries, the superincumbent beds of clay by the steady removal of the sand through innumerable springs. A slight earthquake wave would destroy the equilibrium of a region thus undermined, resulting in the sinking of some areas, and the elevation of others, thus producing such conditions as were described by various observers who witnessed the castrophe of 1811.

The escape of gas resulting from decaying organic matter may have had something to do with the certain phenomena of the earthquake, and would certainly account for the presence of so-called "sulphurous vapors" and gases referred to by so many observers in their accounts of the earthquake.

CONCLUSIONS

The facts here given present an explanation of the elevation and depression of the land in the New Madrid region that has not before been recognized, and the writer believes that they form a satisfactory explanation of the phenomena which have so long puzzled those who have attempted to solve the problem of the great local disturbance at New Madrid. If this is so, they may also explain similar instances of subsidence and elevation in other regions that have been little understood, and will demonstrate, for the artesian waters of the globe, a wider influence as a geologic agent than has hitherto been ascribed to them.

STRUCTURES OF BASIN RANGES

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Several memoirs recently published have awakened a new interest in the geotectonics of the Great Basin region. The main structural features about which discussion centers appears to be whether the Basin ranges are the result of normal faulting and form "block" mountains; or whether the "block" aspect is only apparent, in reality the "block" originally being a sharp asymmetric fold, in which subsequent erosion wears off the steeper limb faster than the other.

In the elucidation of the arguments by specific example, it is unfortunate that some of the illustrations selected have not been chosen with greater discernment. It is now well understood that some of the instances noted furnish the most conclusive proofs of directly the contrary of the purpose for which they were cited. Without entering into detail in regard to many of these cited examples from other parts of the Basin region, it seems pertinent at this time to call attention briefly to certain features displayed in the New Mexican part of the field. These may help to explain similar phenomena in other districts.

The geologic sequence in central New Mexico is especially noteworthy on account of the almost complete absence of the Lower Paleozoic rocks and the enormous development of the Cenozoic strata. The important member of the sequence above the Proterozoic metamorphics is the Upper Carboniferous limestone which attains a normal thickness of 2,000 feet.

In all of the mountain ranges of central New Mexico, appearing as tilted blocks, the crests of which rise 3,000–5,000 feet above the bases, the great Carboniferous limestone forms the backslope, usually reaching to the summit. On the opposite or steep face of the ridges the Proterozoic clastics and schists, which usually stand on edge, are exposed for a vertical distance of 2,000 feet, or more. Above the Carboniferous limestones at the foot of the mountains are Red Beds and then Cretaceous sandstones.

No evidence has yet been found that would indicate that any of these numerous mountain blocks were produced by folding. All observations go to show most conclusively that only faulting is involved. The sedimentaries of some of these mountains, however, are often folded and closely corrugated. Thrust-planes are plainly visible. Numerous other indications point to tremendous compression at some time or other. But the period of compressive action has been found to be a very different one from that during which the present mountains were formed. The compression took place long before the existing mountain blocks reared their heads above the

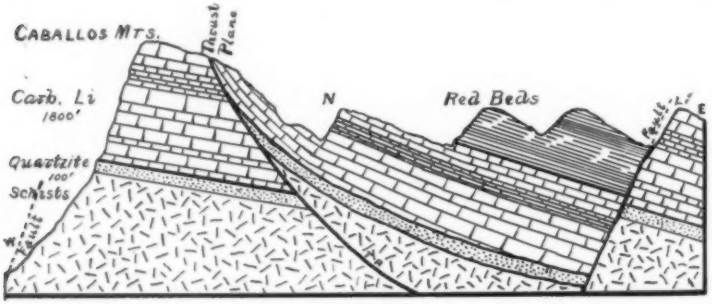

FIG. 1

vast surrounding plains. Chronologically this period of compressive conditions was manifestly after the Carboniferous, because the rocks of this age were involved; but it was before the late Cretaceous, since Cretaceous strata are as clearly not affected.

In the Sierra de los Caballos, in south-central New Mexico, the geological sections are particularly instructive. Near the highest point of the range, known as Timber Peak, the scarp is over 3,000 feet high and displays an excellent exposure of the rocks throughout this entire vertical distance. The transverse section shown a short distance to the north is represented in the diagram, Fig. 1. The heavy line *T. P.* indicates the position of an exceedingly well-displayed thrust-plane. Along it the beds are highly contorted. The entire limestone is badly shattered and traversed by large and small crevices which are now cemented by calc-spar. The inclination of the thrust-plane is now rather steep, but, as will appear subsequently,

this is due partly to the fact that the present position of this structure is not the original one. Since its formation the thrust-plane also has been tilted in marked degree. In point of time, the formation of the thrust-plane long antedates the uprising of the present mountain blocks.

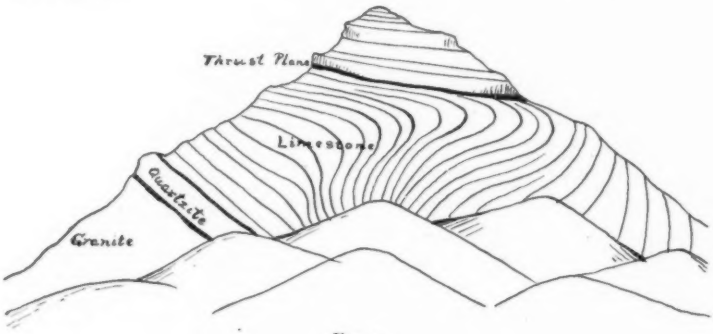

FIG. 2

A few miles to the north, in the same range, is another lofty point called Caballo Peak. There are clearly shown in this place the limestone beds completely overriding the lower beds, the first mentioned now reposing nearly horizontally on inclined strata. Fig. 2 is a sketch of the peak as it appears from the south.

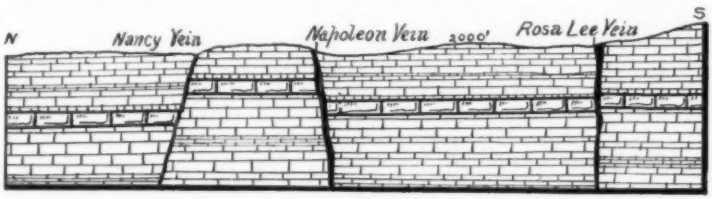

FIG. 3

Another system of faults, the age of which is quite recent, also exists. These dislocations run transverse to the other two and to the axis of the range. As they appear in the canyon walls (at *N*, Fig. 1), a sketch of them (Fig. 3) is annexed.

There are, then, in the Sierra de los Caballos at least three very distinct periods of faulting. The first was before the formation of

the present mountain ridge; a second was coeval with its formation; and the third was long subsequent to its uprising.

Were it not for exceptionally clear evidence to the contrary, casual examination could very easily lead to the conclusion that the Caballos mountain range was produced by sharp folding and that the crest of this asymmetric fold was removed through erosion. This deduction is a quite natural one, especially when, in a view from the summit of the range, there are clearly shown the strata dipping eastward forming a broad syncline and coming up again with westerly dips in the great San Andreas Mountain block, 30 miles beyond.

It so happens that in the instance under consideration we now know enough of the general geological history of the region to give us a good insight into some of the actual conditions that have existed. It has recently been shown[1] that the Upper Cretaceous of central New Mexico rests in marked unconformity upon the older rocks. The period during which conditions existed for folding of the strata was, already stated, later than the laying down of the Carboniferous limestones and later than the deposition of the "Red Beds," as these were all involved.

A number of observations lately made emphasize the character of the events which took place in the region during early Cretaceous times, and the great importance of the unconformity at the base of the Cretaceous of the region. That during this period the older rocks were greatly disturbed over wide areas is amply attested by the almost vertical "Red Beds" (Carbo-Triassic) overlain by horizontal Cretaceous, as is seen at Tejon, south of Santa Fé, in Sandoval county;[2] the highly inclined Carboniferous limestones, on either side of high trachyte dikes on which recline nearly horizontal Cretaceous sandstones on the Chupadera Mesa, in eastern Socorro county;[3] and the position of the Cretaceous on the older formations in the Caballos Mountains in Sierra county; as well as in other localities. The unconformity represents a great land surface; and during the interval for which it stands the strata of the region were folded and eroded off to a plain-like surface before being later covered by sediments.

[1] *American Journal of Science* (4), Vol. XVIII (1904), pp. 356–58.

[2] *Ibid.*, p. 357. [3] *Ibid.*, p. 358.

Attention is especially called to these facts for the reason that in some instances cited relative to the structure of Basin ranges it is quite manifest that the proper local interpretations have not been made. It is probable that a large number of other cases will be found to be illy chosen for purposes of type illustration. The observations made in the Sierra de los Caballos are suggestive of similar phenomena occurring in other districts. Critical evidence on the points emphasized is much desired from many other ranges. When once secured, it may do much towards correcting some very erroneous present interpretations.

A generalized geological cross-section of a part of the Basin region of New Mexico more clearly illustrates the type of mountain structure under consideration (Fig. 4).

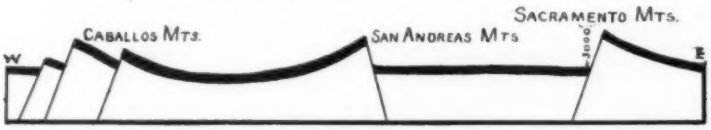

FIG. 4

In all of these ranges there are abundant evidences of marked compression producing the phenomena of folding and thrusting. Yet in every instance thus far observed the period of this movement is found to be long prior to the elevation of the present mountains.

There is another very deceptive feature connected with the formation of the block-like mountains of the New Mexican portion of the Basin region. At the foot of the steeper slope the strata are often found tilted at a high angle, and inclined away from the range. The attitude of the beds easily suggests, at first consideration, the possibility of the mountain ridges being a sharp anticline, with the center completely removed through erosion, leaving the limbs of the arch unequally exposed. This condition might be readily fancied because of the fact that the greater part of the height of the mountains, 3,000–4,000 feet, is usually composed of massive crystallines and schists, and the crest and backslope of the limestones.

There are strong reasons for believing that this phenomenon, instead of being ascribed to folding of the asymmetrical type, should be considered an accompaniment of normal faulting. Only the

faulting is on a gigantic scale—a scale very much larger than is usually met with. When the hade is steep, the strata on the down-throw side to a greater or less degree commonly lag, until a considerable zone is produced in which the strata become highly inclined, and in many cases stand even nearly vertically. A typical case is represented below:

In a smaller way we find the same lagging structures accompanying the faulting in coal mines. It is a fact well known to the miners that when the dip lessens a down-slip is soon to be expected.

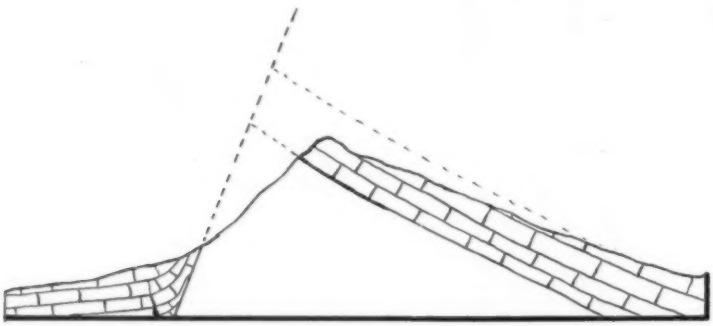

FIG. 5

There is a theoretical reason for believing that in the region under consideration normal faulting, instead of folding, is to be expected to explain the origin of the New Mexican mountains of the Basin district. The principle was clearly set forth by LeConte[1] as long ago as 1889, when discussing the Nevada region between the Sierra Nevada and the Wasatch Mountains.

As considered there and in his textbook of geology[2] this author appears to have regarded the area in question as a region which was subjected to slow and general uprising, but continually adjusting itself through normal faulting in great blocks. By the tilting which these blocks suffered mountain ranges were produced on the elevated edge, and on the depressed side were formed valleys which were subsequently filled with sediments.

[1] *American Journal of Science* (4), Vol. XXXVIII (1889), p. 259.

[2] *Elements of Geology*, 5th ed. (1904), p. 242.

In the late account of the Humboldt region in Nevada, Lauterback[1] dissents somewhat from the view of the simple tilted block idea, and is inclined to believe that the mountain-block and the valley-block are distinct. This appears often to be the correct interpretation in the New Mexican part of the Basin region.

The physiographic development of the New Mexican region appears, briefly to be as follows: About the beginning of Tertiary time the area lying between what is now the Gulf of California and the Gulf of Mexico must have been a vast low-land plain elevated but slightly above sea-level, and having faint relief features. A large part of the plain was a surface worn out on the beveled edges of Cretaceous and older strata, as is, even at the present day, still clearly discernible in its remnants. The Las Vegas plateau, the Llano Estacado, the bolson plains of central New Mexico, and some of the less-broken plains of eastern Arizona appear to belong genetically together. To the east and west of the vast area thus outlined there had been formed, from the sediments derived from the planing off of the central land area, a broad submarine platform. When later in Tertiary times the general bowing up of the region began to take place, the great plain that had been formed was partly a peneplain of destructional land origin and partly a constructional plain of marine origin.

During the period of uprising folds were extensively developed, and the compression was so intense that in many cases thrust-faults were formed. Many low mountain ridges were probably produced at this time. Subsequently, as if the upward movement had been too extensive, the compressive force gave way to one of tension. Normal faulting on a grand scale occurred, producing the numerous short monoclinal or "block" mountains of the region.

Several important points bearing upon Basin Range structures appear to be reached in the present connection:

1. The determination of the most obvious structures of any particular mountain region is not sufficient and is not critical evidence; the time of the formation of the structures is an all-important consideration. When the younger strata are removed from the mountains, the structures of the older rocks may tell a very different story. In some

[1] *Bulletin of the Geological Society of America*, Vol. XV (1904), p. 343.

instances mentioned by Spurr the younger strata would seem to be entirely wanting. In many New Mexico ranges the great Carboniferous limestones form the major portion, and they give evidence of an older and very different record of events from that which includes the uprising of the present mountain blocks.

2. The structures of each mountain range must be determined separately and upon the evidence which it alone presents. Even in neighboring ranges one may disclose a history very much longer and older than another.

3. In the New Mexico area orogenic movement, while more or less rhythmic in character, was doubtless continuous since Paleozoic times. At least three periods of marked activity have been recognized.

4. Modern ranges, the "block" mountains rising out of the Basin plains, in which the Mesozoic strata are eroded from the summits, are likely to have the structures of the first period of orogenic movement (early Cretaceous) most in evidence, and the later effects may be less strongly emphasized. In the specific cases of New Mexico this period was one of folding and overthrusting.

6. Modern mountains, around which there are late lava flows, are likely to show the effects of the third (Pleistocene) movements. These are chiefly normal faulting.

THE CLASSIFICATION OF THE UPPER CRETACEOUS FORMATIONS AND FAUNAS OF NEW JERSEY[1]

STUART WELLER
The University of Chicago

Since the organization of the present Geological Survey of New Jersey, three classifications of the Cretaceous formations of the state have been proposed and have been published in the reports of the Survey. The first of these, elaborated by Professor Cook during his administration as state geologist, was published in 1868.[2] At that time the practice of naming geological formations by geographical names was not usually adopted by working geologists, and the successive beds were designated by names suggested by their lithologic characters. Above the "plastic clays" since known as the Raritan formation two major series of beds were recognized, the "clay-marl" series below and the "marl" series above. The discrimination of the beds of the "marl" series, as first described by Cook, has not been changed by any of the more recent investigations, but a closer study of the "clay-marl" series has led to the discrimination of a series of beds not recognized by Cook. In his interpretation of the stratigraphy of the southern portion of the area, however, Cook, in the absence of accurate topographic maps, fell into one error on account of his failure to recognize the disappearance of his "red sand" formation in that direction, and the consequent continuity of the "lower" and "middle" marl beds. To the south he identified a bed now known to belong in the "clay-marl" series, with the "lower marl" of Monmouth County, and considered the bed now known to represent the combined "lower" and "middle" marls, to be the continuation of the "middle" marl alone.

In 1891 Professor W. B. Clark entered upon a study of the Cretaceous beds of New Jersey, and the results of his work are published in the *Annual Reports* of the Survey for 1892, 1893, and 1897. The

[1] Published by permission of the State Geologist of New Jersey.

[2] *Geology of New Jersey*, 1868, p. 241.

two essential differences between his classification and that of Cook are in the position of the major dividing line between what are, roughly speaking, Cook's "clay-marl" and "marl" series, and in the interpretation of the "yellow sand" formation above the "middle marl." In place of Cook's lithologic names, however, Clark substituted a series of geographic names in accordance with more modern usage. In a more recent paper Clark[1] has made some modification of his earlier interpretation of the beds, notably in the position of the lower boundary line of his lower or Matawan division in the region adjacent to Raritan Bay. In this paper he has excluded the Cliffwood clays from the Matawan, thus bringing the basal line of the Matawan to conform exactly with the base of Knapp's Merchantville clay.

During his study of the Pleistocene deposits under the direction of Professor R. D. Salisbury, Mr. G. N. Knapp found it necessary to make close study of the underlying formations of Cretaceous age. In the course of this study he was able to discriminate a series of five distinct formations in the old "clay-marl" series of Cook. Each one of these formations was found to be marked by constant lithologic characteristics, but at that time the paleontologic characters of the beds had not been investigated. These formations were traced by Knapp and carefully mapped entirely across the state from Monmouth to Salem Counties. A description of the beds, especially in relation to the soils to which they give rise, was first published by Professor Salisbury in the 1898 *Report* of the Survey,[2] and geographic names were applied to them, viz., Merchantville, Woodbury, Columbus, Marshalltown, and Wenonah. A fuller description of the lithologic characters of these formations has been given by Dr. H. B. Kümmel in the recent *Clay Report* of the Survey.[3]

[1] *American Journal of Science*, 4th series, Vol. XVIII, pp. 435–40.

[2] *Annual Report of the State Geologist of New Jersey*, 1898, pp. 35, 36. It may be said that the tracing out of the Cretaceous beds was no part of Professor Salisbury's plan. It was done by Mr. Knapp because the several beds of the "clay-marl" series sustained very definite relations to the Pleistocene formations. The names published at this time were not published by Professor Salisbury for the purpose of making a new classification of the Cretaceous, but merely because the soils could best be described in connection with these several subdivisions.

[3] Geological Survey of New Jersey, *Final Report*, Vol. VI, pp. 152–61.

These three systems of classification have been arranged side by side in the accompanying tables, in order that they may be easily compared one with the other.[1] At the time of publication of Cook's classification, although a large number of Cretaceous fossils had been described from New Jersey, little was known of the actual distribution of the fossil species in these beds, except in the case of the conspicuous shell beds which can be recognized continuously across the state. Cook's classification may therefore be considered as being based almost exclusively upon the lithologic characters of the beds. Before Clark's classification was proposed, however, Whitfield's[2] two important volumes upon the paleontology of the Cretaceous formations of New Jersey had been published, and Clark gives long lists of fossil species in his papers as representative of the faunas of his major divisions, so that his classification was founded, at least in part, upon paleontologic data. Knapp's subdivisions of the "clay-marl" series are professedly based upon the lithologic characters alone.

During the field seasons of 1903 and 1904 the writer has been engaged in an investigation of the paleontology of these Cretaceous beds and has accumulated a large amount of information in regard to the faunas of the successive formations, especially those of the "clay-marl" series, and in the following pages an attempt will be made to point out the bearing which this new evidence has upon the classification of the formations and faunas.

In his Matawan division, Clark has recognized two formations, the Crosswicks clays and the Hazlet sands. The Crosswicks clays correspond exactly with Cook's "clayey green sand," and with Knapp's two formations, the Merchantville clay-marl and the Woodbury clay; while the Hazlet sands correspond in Monmouth County with Cook's "laminated sands" and with Knapp's two formations, the Columbus sand and the Marshalltown clay-marl, as well as with

[1] In this table Cook's classification of the beds in Monmouth County is recognized. His understanding of the stratigraphy in the south was incomplete, and in that portion of the area he considered Knapp's Marshalltown formation as the equivalent of the "lower marl" and the Wenonah as the equivalent of the "red sand," the true Red Bank sand and the Tinton beds being absent there.

[2] *Paleontology of New Jersey*, Vols. I and II; also *Monographs of U. S. Geological Survey*, Vols. IX and XVIII.

a portion of the Wenonah sand. In his faunal lists Clark does not differentiate the fauna of the Crosswicks clays from that of the Hazlet sand, but gives a single generalized list of species as the fauna of the whole Matawan. As a matter of fact, there is considerable community of characters among the faunas of all five formations recognized by Knapp in the "clay-marl" series, except only the fauna of the upper beds of the Wenonah sand in the southern portion of the area, enough, at least, to make their inclusion in one major division fully justifiable. The two cephalopod genera, *Placenticeras* and *Scaphites*, characterize the whole series of beds, either one or both being present at every locality where fossils have been extensively collected, while neither of them has been detected in the higher beds. There are, however, sharp distinctions between the faunas of the successive formations recognized by Knapp, and these faunal characters are easily recognizable throughout the whole extent of the beds across the state, wherever fossils have been found. In the discrimination of these faunal zones of the "clay-marl" division, however, it is not safe to assert that any particular species is absent from any one of the faunas, and bare lists of species, without some statement of the abundance of the forms noted, might not in all cases show the characteristic features of the different faunules. The combined faunas of the whole series of formations, and even including those to the summit of Clark's Monmouth division, really make one unit of a larger order. The constant recurrence of various species and groups of species, in this entire series of faunal zones, indicates that somewhere along the Atlantic border they lived continuously. As local conditions of environment changed from time to time, the dominant characteristics of the local faunas changed, and it is such changes, for the most part but not wholly, that are recorded in the faunas of these New Jersey formations.

The Merchantville clay is characterized by the abundance, among other species, of *Axinea mortoni*, *Idonearca antrosa*, *Trigonia eufaulensis*, and *Panopea decisa*. In the Woodbury clay these same species are conspicuous for their absence or great rarity. In a collection from the Woodbury clay in Monmouth County, including sixty or more species and many hundreds of individuals, a single specimen of *Idonearca* and a single *Axinea mortoni* were found; while, on the

other hand, *Cyprimeria, Lucina cretacea, Breviarca, Cancellaria subalta*, and others which were rare or entirely absent from the Merchantville, are the commonest species of the fauna. Furthermore, this same faunal distinction between the two beds holds as sharply in the region opposite Philadelphia as in Monmouth County. The faunal lists of the Matawan, heretofore published, omit many of the most abundant and widespread species of the Woodbury clay, and are predominantly of Merchantville species, so that the Matawan fauna as previously recorded is somewhat incomplete.

The Columbus sand has as yet not yielded a single fossil, and is perhaps entirely barren. The Marshalltown formation, however, in its more southern extent is abundantly fossiliferous, although in Monmouth County no fossils have yet been found. Near Swedesboro the fossils in this bed occur in a remarkably perfect state of preservation and in great numbers. A large *Trigonia*, probably *T. mortoni*, is represented by hundreds of individuals, and associated with this species are *Cyprimeria sp.* and *Idonearca vulgaris* in abundance. In this fauna the large and ponderous specimens of *Gryphaea vesicularis* and *Exogyra costata*, with innumerable specimens of a variety of *Ostrea larva*, are a conspicuous faunal element for the first time, foreshadowing, perhaps, the Navesink fauna. The whole complexion of the fauna is different from either the Merchantville or the Woodbury, although certain species are present which occur also in one or both of these lower faunas.

Between the Marshalltown clay-marl and the "lower" or Navesink marl there is a well-marked sand bed 40–60 feet thick. In Monmouth County it is, on the whole, a fine micaceous sand, with some clay laminæ and locally near its base with thicker clay lenses. Locally its upper portion is a coarser quartz sand, with a commingling of glauconite near the marl bed. In the southern counties it is predominantly a coarse quartz sand with some disseminated glauconite, the fine micaceous phase being inconspicuous or even perhaps entirely absent. This formation Knapp called the Wenonah sand.

In Monmouth County Clark's Hazlet sands correspond exactly with Cook's "laminated sand," and almost exactly with Knapp's three formations—the Columbus sand, Marshalltown clay-marl, and the Wenonah sand—the upper few feet of the latter being apparently

Cook, 1868		Clark, 1892–1904		Knapp-Kümmel, 1898–1904	Weller, 1905	
Upper Marl	Ash Marl Green Marl	Manasquan	Manasquan Marl	Upper Marl (in part)	D	Manasquan
Yellow Sand			Yellow sand, later referred to the Miocene	Lime sand (including Yellow Sand)	C	Long Branch
Middle Marl	Yellow limestone and lime-sand	Rancocas	Vincentown			Vincentown
	Shell layer Green Marl Chocolate Marl		Sewell	Middle Marl (Sewell)		Sewell
Red Sand	Indurated green earth	Monmouth	Red Bank Sand	Red Sand (Red Bank Sand)	B	Tinton
	Red Sand Dark micaceous Clay					Red Bank
Lower Marl	Marl and Clay Blue shell Marl Sand Marl		Navesink Marl	Lower Marl (Navesink Marl)		Navesink Mt. Laurel
Clay Marls	Laminated Sands	Matawan	Mount Laurel Sand / Hazlet Sand	Wenonah Sand	A	Wenonah
				Marshalltown Clay-Marl		Marshalltown
				Columbus Sand		Columbus
	Clayey Green Sand		Crosswicks Clay	Woodbury Clay		Woodbury
				Merchantville Clay-Marl		Merchantville

excluded. In the southern counties the Hazlet sands correspond only with Knapp's Columbus and Marshalltown, all of the Wenonah being excluded. The line, therefore, between the Matawan and Monmouth, as these two divisions were defined in 1897, is a line running diagonally across Knapp's Wenonah sand, from near the summit of that formation at Atlantic Highlands to its base in Gloucester and Salem Counties. This lack of agreement between the two interpretations was apparently due to Clark's interpretation of the relations of the coarse, quartz-sand phase of the Wenonah which he called the Mount Laurel sand. In regard to this formation he said:

> They have a thickness of about 5 feet in the vicinity of Atlantic Highlands, which slowly increases to the southward, until in the region to the east of Philadelphia they have increased to over 25 feet. Beyond that point they increase more rapidly throughout the southern counties, reaching 50 feet in Gloucester County and fully 80 feet in the vicinity of Salem.[1]

In New Jersey the lithological change at the top of the Wenonah is much more marked than that at its base, and for this reason the Wenonah sand was grouped by Knapp and Kümmel[2] with the underlying rather than the overlying beds. In effect, therefore, two positions for a major dividing line in this portion of the section have been suggested: (*a*) diagonally across the Wenonah sand; and (*b*) at the top of the Wenonah sand.

The recent paleontological studies cast some light upon this problem, even although they do not definitely settle it.

The Wenonah sand, so far as known at present, carries two different faunas. One of these has been found in Monmouth County, and at two localities from which extensive collections have been made over one hundred species have been recognized. This is very different from that in the overlying Navesink marl, and for the present will be referred to as the Wenonah fauna, although ultimately it may be best to give it a different name. The other fauna occurs in Gloucester and Salem Counties, and will be described in connection with that of the Navesink marl.

At one of the localities where the Wenonah fauna has been found the fossils occur in a coarse ferruginous sand at a distance of 9 feet

[1] *Annual Report of the State Geologist of New Jersey*, 1897, p. 183; also *Bulletin of the Geological Society of America*, Vol. VIII, p. 334.

[2] *Loc. cit.*

beneath the base of the Navesink marl. The other locality is in a fine, more micaceous and argillaceous bed, immediately beneath the marl.

In this Wenonah fauna there is a return of many Merchantville and Woodbury species, among them being *Trigonia eufaulensis*, *Axinea mortoni* and *Panopea decisa*. *Idonearca* is also present, but is much less conspicuous than in the Merchantville or the Marshalltown. Among the Woodbury species which occur in the Wenonah fauna, may be mentioned *Cymella bella*, which, although rarely present in the Merchantville, was much more conspicuous in the Woodbury fauua. *Leptosolen biplicata* is one of the very common forms in the Wenonah fauna which was present both in the Woodbury and the Merchantville. The ponderous *Gryphaea* and *Exogyra* of the Marshalltown fauna are absent, but *Ostrea plumosa* is sometimes a very common species.

The faunal change in passing from the Wenonah to the Navesink formations in Monmouth County is far greater than the change in passing over the line between any two of the formations below. In the fauna of the Navesink marl a new factor is introduced which is entirely foreign to the earlier faunas of the area, the most characteristic species of this new element being the cephalopod *Belemnitella americana* and the brachiopod *Terebratella plicata*, both of which are especially abundant and characteristic of this zone. We also find a recurrence of the massive *Gryphaea vesicularis* and *Exogyra costata* which characterized the Marshalltown beds below, but the *Exogyra* is usually less abundant than in the earlier fauna. *Ostrea larva* also occurs in great abundance, as it did in the Marshalltown fauna, but it is a somewhat different variety of the species. In place of the cephalopods *Placenticeras* and *Scaphites* of the "clay-marl" faunas, *Nautilus dekayi* occurs in this fauna and also in the fauna of the Red Bank sand next above. In the fauna of the beds just beneath the base of the Navesink marl, *Placenticeras placenta* occurs more frequently than in any other bed of the New Jersey Cretaceous, associated with many other species common also to the Merchantville or Woodbury formations. These facts, taken together with the marked lithological change at the top of the Wenonah, are strong evidence for placing the major dividing line in this portion

of the New Jersey Cretaceous at the base of the Navesink marl in Monmouth County. But there are other facts to be considered.

One of the most characteristic faunal features of the Navesink marl is a conspicuous shell bed about 12 feet above the base of the marl in Monmouth County. It is usually about 1 foot in thickness, and is composed almost exclusively of the shells of *Gryphaea vesicularis* and *Ostrea larva*, with occasional specimens of other pelecypods and gasteropods. At the base of the Navesink in Monmouth County there is sometimes an arenaceous, more or less abundantly fossiliferous bed, which Cook designated as the "sand-marl." At Atlantic Highlands this bed is 3 or 4 feet thick, and is evidently the bed which Clark mentioned in his description of the Mount Laurel sand at that locality, and which Knapp regarded as forming the top of his Wenonah sand. In passing to the southward this arenaceous basal member of the Navesink seems to become more and more conspicuous, replacing higher and higher beds of the green-sand marl, until at Mullica Hill it extends up to and even includes the conspicuous shell layer of the formation. This arenaceous facies of the Navesink frequently abounds in fossils, although they are usually imperfectly preserved casts, and the fauna is always characterized by the typical Navesink species *Belemnitella americana*.

It is believed that Clark's conception of the Mount Laurel sand formation has grown out from this changing facies of the Navesink to the southward, and, in the absence of sufficient data concerning the fauna of the beds immediately beneath those with the *Belemnitella* fauna, he has extended the Mount Laurel formation downward to include the entire sand bed to the top of the Marshalltown clay. On the other hand, Knapp and Kümmel have extended the Wenonah formation upward to include all the sand to the south, so that their upper boundary line of that formation marks a higher and higher geologic horizon in that direction. From the standpoint of the faunas the major division line in this portion of the Cretaceous beds must be drawn where the *Belemnitella* fauna is introduced, and although the Wenonah fauna of Monmouth County has not yet been detected in the more southern portion of the area, neither has the *Belemnitella* fauna been observed in the lower portion of this Mount Laurel-Wenonah sand, 18 feet beneath the top of the sand

being the lowest horizon where the *Belemnitella* fauna has been seen in New Jersey.

With this interpretation it is possible that both the terms, "Mount Laurel" and "Wenonah," should be retained in the nomenclature of these beds, the Wenonah for the sand formation beneath the beds bearing the *Belemnitella* fauna in Monmouth County and for the southern continuation of the same beds, while the name "Mount Laurel" will designate the arenaceous facies of the Navesink which becomes more and more conspicuous to the south. These relations, however, complicate the task of mapping the beds in the southern portion of the New Jersey area, because of the juxtaposition of the two arenaceous formations whose separation can be based only upon the presence or absence of the *Belemnitella* fauna. However, further observations upon these beds must be made before the relations here suggested can be considered as established.

The fauna of the Red Bank sand is to some extent a recurrence of the faunas of the beds beneath the Navesink marl, *Trigonia eufaulensis*, *Axinea mortoni* and other species of the Merchantville, Woodbury, and Wenonah formations being commonly present. Some species, such as *Perrisonota protexta* and *Corbula crassiplica*, which were present, although usually rare, in one or more of the "clay-marl" formations, become much more abundant in the Red Bank. The fauna is characterized everywhere by the large shells of *Gryphaea vesicularis* and by *Ostrea larva*, species which were abundant in none of these lower formations except the Marshalltown; but they never form such a shell bed as that which occurs so commonly in the midst of the Navesink marl. Other elements in the fauna are also inherited from the Navesink, although the two most characteristic Navesink species, *Belemnitella americana* and *Terebratella plicata*, have nowhere been observed in the fauna.

In none of the classifications as published, except Cook's, is any special recognition given to the hard, glauconitic, indurated sand bed at the top of the Red Bank, although it was briefly referred to by Clark, and has been carefully mapped by Knapp. This bed, called by Cook the "indurated green earth," marks a definite horizon and yields a fauna which especially characterizes it throughout its entire extent. The most characteristic member of this fauna is the

large ammonite *Sphenodiscus*, which has frequently been collected from this horizon, but has not been observed elsewhere. Another very characteristic species is *Trigonia caerulea*, which has been seen only in this formation, and almost everywhere the beds furnish numerous crustacean claws probably belonging to the genus *Callianassa*. A fine exposure of this formation occurs at Tinton Falls, N. J., where this hard bed, 22 feet thick, is responsible for a waterfall in a tributary of the Swimming River, and the name "Tinton beds" may be used to designate the formation. The fauna of the Tinton beds is much more closely allied to the faunas of the beds below than to those above, many of the earlier species being present, while *Terebratula harlani*, the most characteristic species of the next higher division, has never been observed.

Judging from their faunas, the three formations—Navesink (including that portion of the underlying sand with the *Belemnitella* fauna), Red Bank, and Tinton—constitute together a major division of the entire Cretaceous series, comparable in rank with the five formations of the "clay-marl" series, and Clark's name "Monmouth" very nearly expresses the limits of the division.

The Rancocas division of Clark, if some modification of interpretation be admitted, is another natural paleontologic division, characterized by the brachiopod *Terebratula harlani*, but the later investigations of the New Jersey Survey have thrown much light upon this portion of the Cretaceous section. The Sewell marl rarely contains fossils except at its summit, where a very constant shell layer of about 5 feet thickness occurs, being made up almost exclusively of the shells of *Gryphaea vesicularis* and *Terebratula harlani*. The Vincentown formation consists in large part of calcium carbonate furnished by immense numbers of several species of bryozoans. The remains of echinoids are also more or less common, and in the past some very fine specimens of these fossils have been found in this formation. The Vincentown fauna, however, is so different from that occurring at the summit of the Sewall marl that, were it not for the relationships of the "yellow sand" fauna, which combines both elements, one would scarcely be justified in including the Sewell and the Vincentown under one larger division.

In Cook's original classification of the Cretaceous beds of New

Jersey the stratigraphic position of the "yellow sand" was considered to be above the "lime sand" or Vincentown formation of Clark, and it was believed to be intimately related to that formation. But Clark, from his published statements, seems to have been somewhat uncertain in regard to the relationships of this bed.[1] It appears that, while at first he was inclined to follow Cook in including the "yellow sand" in the Cretaceous, yet at a later date he arrived at a different conclusion and considered the beds to be of Miocene age.

A careful search by the writer, in company with Knapp, disclosed good fossils in the "yellow sand" at several localities, and fragments of fossils may be found in the formation at almost every exposure. At the base of Gold Hill, one mile south of Eatontown, *Terebratula harlani* and *Gryphaea vesicularis* occur in abundance, and with them fragments of spines and plates of echinoids, and broken bryozoans. At California Hill, near Deal, fossils occur near the summit of the formation in abundance, *Terebratula harlani* again being the most common form, associated with several species of pelecypods. In the bank of the Manasquan River, at New Bergin Mills, one and one-half miles west of Farmingdale, this formation is well exposed in an unweathered condition, and contains a somewhat larger percentage of glauconite than in the other localities mentioned. Fossils are exceedingly abundant at this locality, some layers of the sand being filled with bryozoan remains, with some echinoids, the fauna being essentially that of the Vincentown lime-sand. In other beds at the same locality, fragments of *Terebratula harlani* were observed.

I have interpreted these fossils as definite evidence that the sand in which they occur is of Cretaceous age, and is to be correlated with the Vincentown lime-sand. If it be thought worth while to designate the "yellow-sand" facies of this formation by a separate name, it may be called the "Long Branch sand," as has been suggested by Knapp.

Clark's contention that the "yellow sand" is Miocene in age is based upon the supposition that the present position of the included fossils is not their original position, but that they have been washed

[1] *Annual Report of the State Geologist of New Jersey*, 1892, p. 205; *ibid.*, 1893, p. 338; *ibid.*, 1897, p. 186; also *Bulletin of the Geological Society of America*, Vol. VIII, p. 336; and *Annual Report*, 1897, p. 190; also *Bulletin*, Vol. VIII, p. 340.

out from their original place of deposition, and have been redeposited in these sands in Miocene time. This interpretation, however, seems to be untenable on account of the stratigraphic relations of the beds, on account of their geographic distribution, and on account of the difference in character between these beds and the dark clay beds which form the base of the undisputed Miocene in the adjacent region. Furthermore, wells drilled to the south of the outcrop of the "yellow sand" show the presence of a similar arenaceous bed beneath the Manasquan marl.

If the reference of these beds to the Cretaceous is correct, it shows that the *Terebratula harlani* zone has a much greater vertical range in New Jersey than the shell bed at the summit of the Sewell marl, in this respect corresponding with the conditions in Maryland where, Clark says, "the *Terebratula harlani* is no longer limited to its former horizon at the top of the Sewell marls, but occurs frequently within and even at the top of the lime-sands."[1]

As regards the "upper" or Manasquan marl of Clark, there is no difference of opinion, except as Clark's earlier interpretation of the "yellow sand" affected the lower limits of the formation in his original definition. The fauna differs in most of its species from the lower faunas, *Caryatis veta* and *Crassatella delawarensis* being two species usually found in this horizon and not observed elsewhere. The bed is especially characterized by the large number of sharks' teeth it contains. The higher beds of the "upper marl," separated by Clark as the Shark River formation, are recognized, by everyone who has studied them, as of Eocene age, and therefore they need no further consideration here.

From the view-point of the writer, the arrangement of the formations, as expressed in the fourth column of the table on p. 76, seems best to express the true faunal relationship of the beds. With the exception of the Tinton beds and the Long Branch sand, no new names are introduced. For the designation of the four major divisions the letters A, B, C, and D are used, instead of Clark's four names "Matawan," "Monmouth," "Rancocas," and "Manasquan," these divisions being strictly faunal, while Clark's names were proposed to designate stratigraphic divisions.

[1] *Annual Report of the State Geologist of New Jersey*, 1897, p. 189; also *Bulletin of the Geological Society of America*, Vol. VIII, p. 339.

In conclusion, the following summation of results in connection with recent investigations upon the Cretaceous formations and faunas of New Jersey may be made.

1. Cook's classification fully differentiated all the beds of the "marl" series that have been recognized since his investigations were carried on, but the "clay-marl" series has been more fully divided since his work was completed. He was in error, however, in applying his classification to the southern counties.

2. In the discrimination of beds, Clark's classification is in the main that of Cook, his contribution being a modernization of the older classification by the introduction of geographic formation names for Cook's lithologic names, and a grouping of the formations into larger divisions.

3. In so far as the discrimination of beds is concerned, Knapp's differentiation of the "clay-marl" series is a distinct advance over the earlier classification.

4. A study of the paleontology of the "clay-marl" formations of Knapp shows them to be as fully differentiated by their faunas as by their lithologic characters.

5. For both faunal and stratigraphic reasons, the "indurated green earth" of Cook is separated from the Red Bank sand, and is recognized as a distinct formation to which the name Tinton beds is applied.

6. The "yellow sand" is regarded to be of Cretaceous age, as originally interpreted by Cook, and its fauna to be the equivalent of that of the Vincentown lime-sand.

Reviews

Maryland Geological Survey, Miocene. By William Bullock Clark, State Geologist, 1904. 2 vols. (1) Text pp. 1–543 and Plates I–IX; (2) text pp. 1–127 and Plates X–CXXXV.

This volume is an admirable example of the results to be attained by the co-operation of numerous experts organized to elaborate the various aspects of a single problem in geology. Much separate and individual work had already been done on the Miocene deposits of Maryland when this survey began. Under the leadership of Dr. Clark, new collections and new surveys were made, and with the literature and old collections at hand, and by an exhaustive study of the Miocene, its stratigraphy and its faunas, with refiguring of old forms and descriptions of new, a concise but exhaustive monograph of the Maryland Miocene has been produced, interesting to any intelligent reader.

The introductory part is contributed by Dr. Clark. Dr. G. B. Shattuck, who, assisted by other members of the survey, has personally conducted the stratigraphic study in the field, writes the geological part and the discussion of early literature. In this portion is found an exhaustive list of species with their local distribution in eighty-eight separate stations, and general distribution into the five zones into which the Miocene is divided (viz., Calvert, zone 17 [lower bed], and zone 19 [upper bed] of the Choptank [as a whole] and the St. Mary's formations).

Dr. W. H. Dall writes the chapter on the relations of the Miocene of Maryland to that of other regions and to the recent formations. Dr. Dall supplies at the end of this part a valuable list of the species characteristic of the North American Miocene, by which he means "the species which occur only in the Miocene and occur in it from top to bottom . . . . not at every horizon . . . . they have existed throughout the Miocene somewhere, and disappear with the inauguration of the Pliocene" (see p. cliii).

The "Systematic Paleontology" is written by different authors, each taking the group of fossils to which he has given special study. Dr. E. C. Case, Dr. C. R. Eastman, E. O. Ulrich, R. S. Bassler, T. W. Vaughan, Dr. R. M. Bagg, Jr., Dr. Arthur Hollick, Mr. C. S. Boyer, Dr. G. C. Martin, Dr. L. C. Glenn, and Dr. W. B. Clark, each discuss one or more groups of either animals or plants.

A comparison of the Miocene of America with that of Europe suggests to Dr. Dall the following:

The differentiation of faunas was well established before the beginning of the Tertiary, and Eocene faunas in America show American characteristics clearly, as compared with those of Europe. Other differences, suggesting migrations, occur in the relative time of appearance of certain groups; as, for instance, in America, the first influx of Nummulites is in the upper beds of the lower Oligocene, just as they were about to disappear from the European fauna, where they had flourished in myriads at an earlier epoch, though then unknown west of the Atlantic. Thus we may expect and shall find, on an inspection of the American Miocene, both differences and points of agreement. As in Europe, so in America, the Miocene was a period of elevation of plication of the earth's crust with its attendant vulcanism, of denudation of the recently elevated areas, and the formation of extended areas of sediment, formed chiefly of clays, sands, and marls, either consolidated into shales and sandstones, or remaining less compacted. The elevation of middle America and the Antillean region, in harmony with that of southern Europe, seems to have been more or less constant, since no marine Miocene beds have been definitely recognized in this area, and the antecedent Oligocene sediments were elevated several thousand feet, North and South America were united, the island of Florida became attached to the Georgian mainland, and the continent of North America on the whole assumed approximately its present outlines. Some modification of the coast line or sea bottom, supposedly in the vicinity of the Carolinas or possibly connected with the elevation of the Antilles, diverted the warm currents corresponding to the present Gulf Stream so far off-shore in the early part of the Miocene as to permit of the invasion of the southern coast lines by a current of cold water from the north, bringing with it its appropriate fauna and driving southward or exterminating the pre-existent subtropical marine fauna of these shores. This resulted in the most marked faunal change which is revealed by the fossil faunas of the Atlantic coast of America subsequent to the Cretaceous. A cool-temperate fauna for the time replaced the subtropical one normal to these latitudes, and has left its traces on the margin of the continent from Martha's Vineyard Island in Massachusetts south to Fort Worth inlet in east Florida, and westward to the border of the then existing Mississippi embayment.

The deep embayment of the Chesapeake region in Maryland and Virginia has retained the largest and least-disturbed area of the marine Miocene sediments and given its name to them, as typical, on the Atlantic coast, of the faunal remains of this character, which they contain. Contrary to the conditions existing in Europe, in America no marked invasions by the sea or extensive depressions of continental land are characteristic of Miocene time, though in special localities the Miocene sediments transgress the remnants of the Eocene.

Regarding temperature conditions Dr. Dall writes:

We may therefore conclude (1) that the temperature conditions governing the fauna of the Maryland Chesapeake were those of the temperate rather than the boreal or subtropical faunas of the present coast; and (2) that the temperature of the Chesapeake embayment was on the whole somewhat warmer than at present. This is what the genera represented also indicate. Between the several horizons of the Maryland Chesapeake there is but very slight indication of any temperature difference; so far as there is any, it points toward a progressive but slight cooling of the water from the Calvert to the St. Mary's; while the subsequent Pliocene was doubtless accompanied by a change in the opposite direction, a rise of temperature being indicated by the changes in the fauna.

H. S. W.

Preliminary Report on the Geology of the Arbuckle and Wichita Mountains, in Indian Territory and Oklahoma. By JOSEPH A. TAFF. With an Appendix on Reported Ore Deposits of the Wichita Mountains, by H. FOSTER BAIN. (Professional Paper No. 31, U. S. Geological Survey.)

This paper treats of the geology and physiography of the mountains named in the title. In both mountain regions there is a core of pre-Cambrian igneous rock. These rocks are much the same in both regions. The principal varieties in the Arbuckle Mountains are granite, quartz-monzonite, aplite, granite-porphyry, and diabase. In the Wichita Mountains gabbro is present, besides most of the above.

The lowest sedimentary rocks of the Arbuckle Mountain region are referred to the Middle Cambrian, and the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, and Cretaceous systems are all represented. The successive formations are conformable up to the top of the Mississippian. There are unconformities between the Mississippian and the Pennsylvanian, between the Pennsylvanian and the Permian, and between the Lower and Upper Cretaceous. The rocks have been considerably deformed and displaced by folding and faulting.

In the Wichita Mountains the oldest sedimentary rocks are likewise referred to the Middle Cambrian. The other systems represented are the Ordovician and the Permian. The intervening Silurian, Devonian, and Carboniferous beds are supposed to be buried by the Red Beds. The structure of the Wichita Mountains is comparable to that of the Arbuckle Mountains; that is, the beds are deformed both by folding and faulting.

The physical history of the region is outlined as follows: The mid-Carboniferous (Mississippian?) rocks were uplifted and folded, resulting

in mountain conditions; but before the end of the Carboniferous (Pennsylvanian?) these mountains were worn down to moderate relief, and before the Cretaceous they were reduced to a peneplain. The earliest peneplain represented in the region is, therefore, of pre-Cretaceous age.

There is a lower peneplain, partially developed, probably of Tertiary age, which cuts the Cretaceous as well as older rocks, and its surface is 100 to 400 feet below that of the Cretaceous peneplain. A still later cycle of erosion has been begun, and the valleys are now developing new plains 200 feet or so below the Tertiary peneplain.

In the Wichita Mountains, there is nothing to indicate the date of the deformation more closely than that it was somewhere between the Ordovician and Permian; but, in view of the similarity of the structure and of the stratigraphy in the two mountain systems, it is regarded as probable that the deformation in the Wichita Mountains occurred at about the same time as that of the Arbuckle Mountains.

With reference to the reported ore deposits in the Wichita Mountains, an elaborate series of tests of materials collected by Dr. Bain shows nothing of economic importance.

R. D. S.

"On the Evolution of the Proboscidea," *Philosophical Transactions*, London (B), Vol. CXCVI, pp. 99–118.

"The Barypoda, a New Order of Ungulate Mammals," *Geological Magazine*, October, 1904, p. 481.

Of the numerous discoveries of Eocene vertebrates from Africa within the past few years none are of more interest than certain forms referred to the Proboscidea by Dr. Andrews, of the British Museum. He has shown very clearly several of the early stages in the evolution of these animals from small-skulled animals with an almost typical eutherian dentition, the first premolar only being wanting, and the second incisor, the tusk of the elephant only moderately developed and not at all porrected. Hitherto the earliest of the Proboscidea known are from the lowest Miocene of France. the order reaching America in the upper Miocene times. That Africa was the original home of this order of ungulates now seems assured.

Another paper of interest by the same author is that in which he defines a new order of ungulates from the Eocene of Africa, which he has called the Barypoda, a group somewhat intermediate between the Amblypoda (Dinocerata) and the Proboscidea.

S. W. W.